US Army Corps of Engineers
Seattle District

PSDDA Reports

Puget Sound Dredged Disposal Analysis

Washington State Dept. of Natural Resources

BENTHIC RESOURCES ASSESSMENT TECHNIQUE EVALUATION OF POTENTIAL DREDGED MATERIAL DISPOSAL SITES IN PUGET SOUND PHASE II SITES

red by Douglas G. Clarke
Environmental Laboratory
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg Mississippi
and
David Kendall
U.S. Army Corps of Engineers
Seattle District

December 1987

EPA Region 10

ECOLOGY

BENTHIC RESOURCES ASSESSMENT TECHNIQUE EVALUATION OF POTENTIAL DREDGED MATERIAL DISPOSAL SITES IN PUGET SOUND: PHASE II SITES

by

Douglas G. Clarke

Environmental Laboratory
U.S. Army Corps of Engineers
Waterways Experiment Station
Vicksburg, Mississippi

and

David Kendall
U.S. Army Corps of Engineers
Seattle District

December 1987

PREFACE

This investigation was sponsored by the U.S. Army Engineer District, Seattle under Intra-Army Order for Reimbursable Services Number E85-86-3283 and E85-86-3238, dated 15 May and 6 June, 1986 respectively.

The authors of the document were Dr. Douglas G. Clarke of the Coastal Ecology Group (CEG), Environmental Resources Division (ERD), Environmental Laboratory (EL), U.S. Army Engineer Waterways Experiment Station (WES), and Dr. David Kendall of the U.S. Army Engineer District, Seattle, Regulatory Functions Division. The authors acknowledge Ms. Jerre Sims, Mr. Harold Bain, and Mr. Jerry Moss (CEG) for their assistance in laboratory processing of the fish food habits samples and preparation of the figures used in the report. Ms. Virginia Sotler (CEG) performed data reduction and analysis. Mr. Peter Striplin, Evans Hamilton Incorporated, assisted in the field sampling and processed the benthic samples. Work reported herein was conducted under the direct supervision of Mr. Edward J. Pullen, Chief, CEG, and the general supervision of Dr. Conrad J. Kirby, Jr., Chief, ERD, and Dr. John Harrison, Chief, EL.

Commander and Director of WES was COL Dwayne G. Lee, USA. Technical Director was Dr. Robert W. Whalin.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

1. The U.S, Army Engineer District, Seattle is currently involved in a decision-making process regarding the designation of open water dredged material disposal sites in Puget Sound and adjacent waters. In 1985 the Puget Sound Dredged Disposal Analysis (PSDDA) study, a joint effort among the Corps of Engineers, Environmental Protection Agency, and the Washington Departments of Natural Resources and Ecology, was initiated to examine long-term requirements and strategies for open-water disposal of dredged materials. The quality of benthic habitats at proposed disposal sites was identified as a major topic of interest in the PSDDA study because of potential impacts to demersal fish feeding habitat.

2. One aspect of benthic habitat quality is the relative amount of trophic support that a given benthic habitat provides demersal bottom-feeding fishes. Analytical procedures have been developed at the U.S. Army Engineer Waterways Experiment Station (WES) with funding from the Corps of Engineer's Environmental Impact Research Program to estimate this aspect of benthic habitat quality. These procedures are collectively called the Benthic Resources Assessment Technique, or BRAT (Lunz and Kendall, 1982; Clarke and Lunz, 1985). The BRAT analysis involves the collection of two data sets; one which describes benthic biomass in terms of size and vertical distribution in sediments at selected sites, and a second which describes the foraging depth and prey size exploitation pattern of demersal fishes at those sites. The BRAT then estimates that portion of the total benthic infaunal biomass that is both available and vulnerable to predation by target fishes.

3. During the period of 14-23 July 1987, benthic box-corer and otter trawl samples were collected at three areas identified as zones of siting feasibility (ZSF) for unconfined open-water disposal sites in Puget Sound. This report presents the results of a BRAT analysis of these samples

METHODS

4. Field sampling was performed at three locations: Anderson Island/Devil's Head (ZSF 3), Anderson Island/Ketron Island (ZSF 2), and Bellingham Bay. Specific boundary coordinates for each sampling site were provided by the U.S. Army Engineer District, Seattle. An overview of the study area is depicted in Figure 1. Investigations at these sites represent a second phase of PSDDA and focuses on the Phase II non-dispersive disposal sites. Collected data supplement the results of prior parallel studies at Commencement Bay, Elliott Bay, Port Gardner, and Saratoga Passage. Specific locations of benthic stations and trawl transects were determined based on best available information on site boundaries, benthic and physical characterization data, and previous fisheries resource surveys. In particular, an attempt was made to coordinate trawl stations with those occupied by ongoing fisheries surveys conducted by the University of Washington under contract to the Seattle District of the U.S. Army Corps of Engineers. Due to limits on the total sampling effort imposed by funding constraints, a decision was made to allocate sampling unequally among the

three areas. This approach allowed a more detailed evaluation of selected sites on a prioritized basis. A view of the Anderson Island/Devil's Head (ZSF 3) and Anderson Island/Ketron Island (ZSF 2) study areas is depicted in Figure 2, and the Bellingham Bay study area is shown in Figure 3.

5. Box-coring and otter trawling efforts were conducted from the R/V Kittiwake, owned and operated by Mr. Charles Eaton. Field operations were conducted with the assistance of personnel representing the University of Washington, Evans-Hamilton, Incorporated, the U.S. Army Engineer District, Seattle, and WES.

Benthic Sampling Design

Field Collection and Processing

6. A total of 41 benthic samples were taken among 39 stations at the three sites, with sample allocation as follows: Anderson Island/Devil's Head (ZSF 3) - 11 stations, Anderson Island/Ketron Island (ZSF 2) - 11 stations, and Bellingham Bay - 17 stations. Approximate locations of box core stations are indicated in Figures 2 and 3. At station 8 at ZSF 2 three replicate samples were taken to examine heterogeneity of the benthos at that site. Due to coarse sediments at preselected stations in the southern portions of both ZSF 2 and ZSF 3, box corer penetration was inadequate to obtain samples of the required depth for a BRAT analysis. These stations were reallocated elsewhere in the respective ZSF. An inventory of benthic sample station locations, including Loran coordinates and radar vectors, and water depths is given in Appendix A.

7. Cores were collected by means of a 0.062 sq m Gray O'Hara stainless steel box-corer fitted with a plexiglass liner. As soon as the corer was retrieved and on deck, the liner containing the undisturbed sample was removed from the corer and processed as follows: Beginning at the sediment-water interface the core was divided into 0-2, 2-5, 5-10, and 10-15 cm vertical sections. The 0-2 cm section was washed into a 0.25 mm mesh seive bucket. The remaining vertical sections were individually washed into a 0.5 mm mesh sieve bucket. Each sediment sample was sieved by immersion of the buckets in a 30 gallon upright container filled with ambient seawater, and gently shaken and swirled to suspend the larger material and to allow fine sands, silts and clays to pass through the screens. Residual material was placed in cloth bags that were pre-labelled internally and externally with an indelible marker, tied, and preserved in 10% seawater-buffered formalin The storage container and location of each bag was recorded on a field data sheet. All four vertically sectioned samples were then moved to the laboratory for analysis.

Laboratory Analyses - Benthic Cores

8. Organisms were removed from each of the four vertical depth fractions (0-2, 2-5, 5-10, and 10-15 cm) from each box core, sorted to major taxa and individually separated into discrete size class intervals by a wet sieving procedure as described by Carr and Adams (1973) and Sheridan (1979). Nested, graded 3-inch standard sieves used in the benthic analysis were; 6.35, 3.35, 2.0, 1.0, and 0.5 mm. The sieve series for processing the 0-2 cm depth fraction had one additional sieve with a 0.25 mm mesh size. Each sample was processed as follows: the sample was carefully washed through the

nested sieve series using a gentle water rinse, taking care not to damage soft-bodied benthic organisms. Each sieved sample starting with the 6.35 mm sieve and working down to the appropriate smallest mesh sieve was then vacuum filtered onto 0.45 micron cellulose acetate filters (millipore filter type HA), and next quantitatively transferred to weighing bottles. Taxa sorted from the 0.25 mm sieved sample for the 0-2 cm depth fraction were weighed directly after filtering, as explained below. Wet-weight biomasses were initially recorded to 0.01 g and the sample returned to a properly labelled vial containing 70% alcohol. In some isolated cases, when the available biomass was small, a higher level of accuracy was required (0.1 mg).

9. For the 0-2 cm vertical depth fraction all individuals of each major taxon were enumerated. Approximately 150 individuals of each major taxon were divided into 5 subsamples of 30 individuals each. Each subsample was weighed on an analytical balance to the nearest 0.001 mg. Average individual weight for all five subsamples were then calculated as well as the standard deviation and coefficient of variation. The average individual weight was then used to estimate the total weight of that taxon in the sample by multiplying by the total number of individuals enumerated.

10. Biomass data were converted to g/sq m (wet weights) and incorporated into the overall BRAT evaluation. All samples have been archived.

Fish Food Habits Sampling Design

Field Collection and Processing

11. A total of 27 otter trawl samples were obtained. Fish collections were conducted at each of the study sites concurrently with the benthic sampling. A 25-foot otter trawl was used to collect fish specimens. Sampling was allocated as follows: Anderson Island/Devil's Head (ZSF 3) - 8 trawls, Anderson Island/Ketron Island (ZSF 2) - 7 trawls, and Bellingham Bay - 12 trawls. Approximate locations of the trawl transects are noted in Figures 2 and 3. The catch at each study area was divided as follows: trawls (1-3) in the northern section of ZSF 2, trawls (4-6) in the southern section of ZSF 2, trawls in the ZSF 2 reference area, trawls (1-2) in the northern section of ZSF 3, trawls (3-4) in the middle zone of ZSF 3, trawls (5-6) in the southern section of ZSF 3, trawls in the ZSF 3 reference areas (A, B), trawls in the southern section of Bellingham Bay, and trawls in the northern section of Bellingham Bay.

12. Trawls were of relatively short duration in order to minimize deterioration and regurgitation of the gut contents. Target benthic feeding fish species representative of demersal fishes utilizing each site included the English sole (Parophrys vetulus), Dover sole (Microstomus pacificus), rex sole (Glyptocephalus zachirus), starry flounder (Platichthys stellatus), butter sole (Isopsetta isolepis), rock sole (Lepidopsetta bilineata), and snake prickleback (Lumpenus sagitta). Fish collection efforts were directed by the number and composition of the catch at each study site. Fishes collected along each transect were processed as follows: (a) demersal bottom-feeding fishes were separated from pelagic fishes, which do not have value in the analysis, (b) the demersal fish catch was sorted by species and each species was divided into Standard Length (SL) size classes of 5-9.9, 10-14.9, 15-19.9, 20-24.9, 25-29.9, and greater than 30 cm, (c) all

individuals of the same species and size class captured at the same location were processed for food habits analysis according to the procedures described by Borgeson (1963). In brief, contents of multiple stomachs are dispersed into the same container with buffered 10% formalin. This procedure pools the variability between diets of individuals of the same species and size to yield a sample representative of the diet of an average individual feeding at a particular site. The procedure also preserves the integrity of individual food items that commonly become entangled and difficult to separate and identify when fixed within a fish's stomach as per more traditional techniques.

Laboratory Processing - Fish Food Habits

13. Stomach contents representing individual species size class samples were picked and sorted to major taxonomic categories (e.g., Mollusca, Annelida, Crustacea, etc.). Fish prey items were placed under the general category Nekton. Sorted-by-taxon samples were individually separated into discrete size class categories by a wet-sieving procedure described by Carr and Adams (1973) and Sheridan (1979). Wet-sieving was accomplished using a 3-inch diameter set of nested sieves from top to bottom in the following sequence: 6.35, 3.35, 2.0, 1.0, 0.5, 0.25, and 0.063 mm. In a manner similar to the treatment of the benthic samples, the stomach contents from each sieve were vacuum-filtered onto pre-weighed 0.45 micron cellulose acetate filters. This step stabilized the sample by removing free water. Wet-weights were recorded to the nearest 0.01g and the sample returned to a labelled container with 70% alcohol. Weights were tabulated by site, predator species, major taxon, and sieve size category. All samples have been preserved in 70% isopropyl alcohol and archived.

Data Analysis

14. The data sets created by the field and laboratory efforts described above form the input to the BRAT evaluation. Based on examination of the fish food habits data, that component of the total benthic biomass that is both available and vulnerable to predation by the target fish species is estimated. This determination involves assignment of each fish size class sample to groups based upon their particular prey-size exploitation pattern. Percent biomass data were subjected to cluster analysis (numerical classification: Bray-Curtis similarity coefficient, group averaging sorting strategy) to objectively assign food habits samples, each representing a fish species-size class-location combination, to a feeding strategy group based on similarities in prey-size exploitation behavior. From the prey-size exploitation data, an estimate of the size range of prey utilized by, or vulnerable to given target predators is obtained. The stomach contents data are also used to estimate the foraging depth of each species size class sample. This is done by examination of the taxonomic composition of benthic prey in each food habits sample as compared to observations of the vertical distribution of prey taxa in the box-corer collections.

15. An examination of the raw benthic data indicated that several large patches of biomass, particularly in the deeper sediment fractions, were contributed by large bivalve molluscs. These large bivalves, as evidenced by the stomach contents data, were not utilzed as prey items by any of the target fishes. Therefore, because their large biomasses would otherwise mask the importance of contributions made by the remaining benthic taxa, these

large bivalves were selectively deleted from the benthic data set. Biomass deletions were limited to stations 1 and 9 in ZSF 3 impact area, station 2 in ZSF 3 reference area, and station 7 in Bellingham Bay South study area. All deletions represented biomass in the 10-15 cm sediment depth interval.

16. For each cumulative (0-2, 0-5, 0-10, 0-15 cm) sediment depth fraction, size-partitioned biomass data for all non-deleted taxa were subjected to cluster analysis (Bray-Curtis similarity coefficient, square root transformation, group averaging sorting strategy) to assign benthic samples to groups or "strata" on the basis of their similarities in benthos-size distribution and relative biomass contribution. Patterns of high or low benthic biomass and size distribution can then be discerned when these data are superimposed on the spatial array of sampling stations.

17. Each benthic biomass stratum is then evaluated in terms of the potential trophic support afforded to each predator group. This step involves summation of the vulnerable (ie. appropriate size range) prey biomass from the sediment surface down to the lowest zone of prey availability (ie. foraging depth). Thus each benthic stratum is given a value in cumulative prey biomass (g/sq m) for each predator group. These values represent the potential prey biomass for target predator species, and allow comparative estimates of the trophic support afforded by different sampling sites to be made.

RESULTS

Box-Corer Samples

Field Observations

18. As stated in the Methods section, a total of forty-one box-core samples was collected. Stations at ZSF 3 ranged in water depth from 48 to 80m; at ZSF 2 from 113 to 136m; at Bellingham Bay from 22 to 31m.

19. Visual inspection of box-corer samples indicated that sediments at most sampling sites were composed of relatively homogeneous silty-clays typical of depositional environments. Difficulties in obtaining box corer samples were encountered at both Anderson Island study areas. Penetration problems reflected a gradient of increasingly coarse sediments running roughly from north to south in each area.

Taxonomic Composition of the Benthos

20. In the BRAT analysis benthic samples are sorted only to major taxonomic categories. Therefore a precise description of taxonomic composition at the family-species level cannot be given. Examination of the changes in percent composition of major taxa among the study areas, however, does reveal some trends in the data. Figure 6 illustrates these changes. Polychaetes represent a major component of the benthos at each study area. Bivalve molluscs form a substantially larger proportion of the benthos in Bellingham Bay than in either Anderson Island study area (note, however, that large bivalve mollusc biomass has been removed from four stations as described in paragraph 15). Ostracods were present in appreciable amounts at the Anderson Island study areas, but were essentially absent from

Bellingham Bay. Ophiuroids were collected in notable quantities in all areas with the exception of Anderson Island/Ketron Island. In terms of biomass, polychaetes generally dominate the benthos at the Anderson Island/Devils Head station groups. Visual inspection of the benthic samples indicated that polychaetes of the families Ophiliidae, Spionidae, and Maldanidae were important members of the infauna. Molluscs, primarily bivalves of the genera Axinopsida and Macoma, were found at all study areas, but were dominant at the Bellingham Bay South stations. The biomass depicted as Other Taxa in Figure 6 is predominantly comprised of cerianthid Anthozoans, or sand anemones.

Spatial Distribution of Benthic Biomass

21. Figure 5 depicts the mean total biomass (0-15 cm sediment depth) at stations within the various study areas. Note that large bivalve biomass has been deleted from these values. Highest mean biomass per station was found at the Anderson Island/Ketron Island (ZSF 2) study area. The lowest value occurred at the Anderson Island/Devils Head reference stations (located both to the north and to the southeast of the actual ZSF 3 area). The northern and southern Bellingham Bay study areas have mean total biomass values (80.84 and 84.04 g/sq m respectively) that are intermediate to those at Ketron Island and Devils Head.

22. Comparisons of vertical distributions of mean total benthic biomass among study areas can be obtained from Figure 7. All five study areas have approximately equivalent amounts of benthic biomass in the 10-15 cm sediment depth level. Most biomass at this depth, with the exception of that portion represented by fauna that vertically migrate, is beyond the foraging depth of most demersal fish predators. The upper two cm of the sediment column, however, which is probably the most important from a trophic support standpoint, shows some substantial differences among the study areas. The pattern is consistent with that for total biomass, i.e., Devils Head showing lowest overall values, Bellingham Bay sites intermediate, and Ketron Island showing the highest value. In the 2-5 cm sediment depth interval, the Bellingham Bay sites, particularly the northern area, show substantially greater amounts of benthic biomass. The Ketron Island reference stations contained the least biomass (6.52 g/sq m) in this sediment depth interval. In the 5-10 cm sediment depth interval, the Devils Head and Bellingham Bay samples revealed approximately equivalent mean total benthic biomass values, generally in the 17-27 g/sq m range. A large concentration of biomass (approximately 47 g/sq m) is found at this sediment depth in the Ketron Island samples.

Size Composition of Benthic Biomass

23. Table 1 presents a compilation of the size-partitioned mean biomass values for major benthic taxa. This breakdown facilitates examination of the data for trends in the mean size of infaunal organisms among study areas. For example, a preponderance of small to intermediate sized benthos is indicative of opportunistic, newly recruited benthos, which characterize recently disturbed benthic communities (Rhoads et al. 1978). In contrast, the presence of larger benthic organisms can be indicative of long-term, stable, equilibrium communities. In this data set the biomasses of bivalve molluscs found at Ketron Island fall into the 3.35 and 6.35 mm size

categories, whereas at the Bellingham Bay study areas a much broader size range is seen, extending down to the 2.00 and 1.00 mm size categories. This may reflect taxonomic differences in the bivalves occurring at each site. Bivalves were essentially absent at the Devils Head areas. Size distributions of polychaete biomass are similar among the Devils Head and Ketron Island sites, where biomass peaked in the 6.35 mm category with additional biomass in the 3.35 mm category. A subtle difference is seen between polychaete size distributions at the Bellingham Bay sites. At the southern stations the majority of polychaete biomass is evenly distributed in the 3.35 and 6.35 mm size categories. In contrast, polychaete biomass at the northern stations peaks in the 3.35 mm category, with secondary packets of biomass in the 2.00 and 1.00 mm categories. The absence of ostracods from the Bellingham Bay sites represents a notable size difference from the Ketron Island and Devils Head sites. Appreciable ostracod biomass occurred in the 1.00 mm size category at Ketron Island. Although mysids/euphausiids did not contribute a substantial amount of biomass in the benthic samples due to their predominantly epibenthic rather than infaunal habits, it should be noted that high densities of these taxa were present at both Ketron Island and Devils Head, as evidenced by the trawl catches. Mysid/euphausiid biomass in the benthic samples therefore does not have direct relevance to their biomass contributions to the diets of fish predators. Ophiuroid biomass occurred primarily in the 2.00 and 3.35 mm size categories except at the northern Bellingham Bay stations, where secondary peaks of biomass extended into the largest size category. Other taxa comprised relatively large amounts of biomass at Ketron Island and northern Bellingham Bay. Other taxa included items such as cerianthid anthozoans and holothuroids, which primarly fell in the 6.35 mm size category.

Benthic Strata

24. Benthic biomass data were clustered using size-partitioned and total biomasses as attributes for each station. Thus stations from different study areas could, based on their similarity in biomass distribution, occur in the same cluster or stratum. Importantly, it should be noted that strata are formed independent of taxonomic composition. In data sets in which there are no remarkable differences among most stations in their size-partitioned biomass distribution, total benthic biomass will drive the groupings of stations into strata. In this data set size differences among stations was sufficient to jointly act with total benthic biomass to determine station cluster composition. Spatial displays of the stations within a stratum can therefore reflect both quantity and size characteristics of the benthos present at each sediment depth level (Figures 6 through 8).

25. Based on the results of the cluster analysis, arbitrary biomass ranges were used in conjunction with predominant size modes to denote benthic strata. Cluster dendrograms for each sediment depth interval are presented in the Appendices. For the 0-2 cm sediment depth fraction a single outlier station (Bellingham Bay - South, station 5) was assigned to Stratum A1. This station had an extremely low total benthic biomass of 0.6 g/sq m and a size mode of 1.00 mm. Stratum A2 consisted of nine stations, seven from the Devils Head area and two from Ketron Island. Four of the Devils Head stations were reference stations. Total benthic biomass ranged from 5.7 to 15.3 g/sq m with a mean of 8.6 g/sq/m. This stratum was characterized by an interesting bimodal size distribution, with most biomass falling into either

the 1.00 or 3.35 mm categories. Stratum A3 had a slightly higher mean total biomass value of 12.4 g/sq m, but differed from Stratum A2 in having a unimodal size distribution in either the 2.00 or 3.35 mm categories. This stratum consisted of six Bellingham Bay stations, with the northern and southern areas having equal representation. Stratum B1 had a mean total biomass of 14.7 g/sq m, and a size mode of 1.00 mm. Five stations formed this stratum, three of which were Ketron Island stations. Stratum B2 had a similar mean total biomass (14.9 g/sq m), but size modes were predominantly in the 2.00 or 3.35 mm categories. Of the ten stations in this stratum, eight were from the Bellingham Bay sites (seven from the southern sector). The remaining two stations were from Devils Head. One of the Devils Head stations was a marginal outlier due to a very low total benthic biomass value of 3.6 g/sq m. Stations grouped into Stratum C1 generally had much higher biomass values, ranging up to 78.3 g/sq m (mean of 34.1 g/sq m). A number of these stations also showed bimodal size distributions, with most biomass falling in the 6.35 and 1.00 mm categories. Nine stations sorted into this stratum, with seven representing Ketron Island stations. Strata comprising the 0-2 cm sediment depth interval show a high degree of sampling area integrity, an indication of subtle but significant differences in the quantities and size characteristics of the surface-dwelling benthos in each study area.

26. For the 0-5 cm sediment depth interval, cluster analysis provided five benthic strata. Stratum A1 consisted of ten stations: six from Devils Head, three from Ketron Island, and one from Bellingham Bay. These stations had total benthic biomasses in the 8.7 to 23.6 g/sq m range, with a mean of 15.1 g/sq m. Size modes were mixed among the 1.00, 2.00, and 3.35 mm categories. Stratum B1 had somewhat higher biomass values in the 15.3 to 32.2 g/sq m range (mean of 22.4 g/sq m). Size modes were primarily in the 3.35 mm category, with shifts to either 2.00 or 6.35 mm at several stations. Eight of eleven stations in Stratum B1 were from Bellingham Bay, and the remaining three from Devils Head. One of the three Devils Head stations was an outlier in terms of modal size. Stratum B2 contained seven stations: five from Ketron Island and two from Devils Head. Although their biomass mean and range values were essentially the same as Stratum B1, their size modes represented somewhat larger benthos, mainly in the 6.35 mm category. Stratum C1 showed distinctly higher total benthic biomasses, ranging from 29.0 to 63.7 g/sq m with a mean of 43.9 g/sq m. All eight stations in this stratum were from Bellingham Bay. A final four stations from Ketron Island formed Stratum D1, which was characterized by very high benthic biomass. These stations retained a semblance of a bimodal size distribution in the 6.35 and 1.00 mm categories.

27. Cluster analysis produced five strata in the 0-10 cm sediment depth interval. Stratum A1 contained four Devils Head stations characterized by relatively low biomasses (mean of 19.0 g/sq m). Size modes were mixed amomg the 1.00, 3.35, and 6.35 mm categories. Stratum B1 stations (six from Bellingham Bay, four from Devils Head, three from Ketron Island) displayed somewhat higher biomass values in the 28.6 to 56.1 g/sq m range (mean of 43.0 g/sq m). These stations were characterized by consistent size modes in the 6.35 and 3.35 mm categories. Stratum C1 consisted of nine Bellingham Bay and two Ketron Island stations. These stations had a mean benthic biomass of 55.7 g/sq m, and size modes in either the 2.00 or 3.35 mm categories. Four stations comprised Stratum C2, having a mean benthic biomass of 68.1 g/sq m, and a 6.35 mm size mode. Stations with very high

benthic biomasses (mean of 119.1 g/sq m) grouped into Stratum D1. Six of eight stations in this stratum were from Ketron Island, and the remaining two from Devils Head. A consistent 6.35 mm size mode was shown.

28. Five strata were formed for the 0-15 cm sediment depth interval. Three Devils Head stations were assigned to Stratum A1. These had very low biomass values, between 25.7 and 31.1 g/sq m. Stratum B1 consisted of thirteen stations of intermediate biomass (mean of 51.9 g/sq m). Six of seven Stratum B2 stations were from Bellingham Bay. This stratum had biomass values similar to B1, with size modes predominantly in the 2.00 mm category. Stratum C1 benthic biomasses were in the 59.9 to 136.4 g/sq m (mean of 90.8 g/sq m). Stratum D1 benthic biomasses fell in the 91.3 to 264.9 g/sq m range (mean of 163.1 g/sq m). With the exception of Stratum B1, biomass size modes for the 0-15 cm sediment depth level were dominated by the 6.35 mm category.

29. Because the number of stations at each study area was limited, Strata A and B were pooled in Figures 6 through 8 to indicate areas of comparatively low biomass. Likewise, Strata C and D were pooled to indicate areas of high biomass. Demarcations between strata are arbitrary, but assist in visualizing trends in the spatial array of biomass data.

30. At Anderson Island/Devils Head (ZSF 3) the surface (0-2 cm) sediment depth interval was characterized by comparatively low benthic biomass values as indicated by the prevalence of strata A and B throughout the area (Figure 6). Note that data for stations in the extreme southern portion of ZSF 3 are lacking due to box-corer penetration problems in the apparently coarse sediments there. Also note the predominance of stratum A2, an indication of similarity of benthos size characteristics as well as biomass concentration. Relatively low biomass levels extend downward to the 0-5 cm sediment depth interval, as all stations fall into either A or B strata. The addition of significant biomass below the 5 cm sediment depth level is shown by the appearance of stratum D1 at two stations in the central portion of zsf 3, a pattern that persists down to the 0-15 cm sediment depth level.

31. At Anderson Island/Ketron Island (ZSF 2) the surficial sediments show comparatively high benthic biomass concentrations, as evidenced by the occurrence of seven stratum C1 stations (Figure 9). Again, note that corer penetration problems prevented the acquisition of benthic data at stations in the southern portion of ZSF 2 as well as at reference stations further to the south of the ZSF boundary. Low biomass stations were found in the northern and eastern portions ZSF 2. Station 8, at which two replicate box cores were taken, fell into the low biomass category. Some degree of patchiness in the benthos is apparent from the variation in strata assignments shown by the station 8 replicates. A more complex pattern of benthic biomass and size distribution is seen in the 0-5 cm sediment depth interval. A mix of high (stratum D1) and low (predominantly stratum B2) biomass values is shown. Several additional stations enter high biomass strata in the 0-10 cm sediment depth interval. Low biomass stations are primarily confined to the eastern side of the ZSF at both the 0-10 and 0-15 cm sediment depth intervals.

32. The Bellingham Bay study areas are characterized by generally low biomass concentrations in the 0-2 cm sediment depth interval (Figure 8). A single station in the northern study area falls into a high biomass stratum.

All stations within the boundaries of the southern study area are members of stratum B2, an indication uniformity among these stations in terms of biomass concentrations and size characteristics. In the 0-5 cm sediment depth interval a shift to higher biomasses is seen, particularly in the central and northern portions of the overall study area. Stratum C1 provides most of the northern coverage, whereas stratum B1 is found to the south. This pattern extends downward to the 0-10 cm sediment depth interval. A shift to lower biomass strata occurs in the 0-15 cm sediment depth interval, reflecting a reduced amount of biomass below 10 cm.

Summary of Benthic Biomass Distribution

33. Figures 9-13 are three-dimensional plots of benthic biomass across size categories and sediment depth intervals. Individual figures present biomass distribution at a given study area (stations pooled). For example, Figure 13 depicts vertical distribution of benthic biomass at the Anderson Island/Devils Head study area. A pattern of large benthic organisms occurring at the deeper sediment depths is revealed. In the uppermost sediment depth fraction, benthic biomass occurs predominantly in the 1.00 mm size category, but a shift to the 3.35 and 6.35 mm size categories is seen in the 2-5 cm depth interval. This pattern persists, with only slight deviation, at the Anderson Island/Ketron Island reference sites (Figure 10), indicating a fundamental similarity in benthic community conditions. The occurrence of large benthic organisms deep in the sediment is indicative of late successional stage communities. A predominance of very small benthos confined to the surficial sediments would, in contrast, be indicative of opportunistic, early successional stage communities. At the Anderson Island/Ketron Island study area (Figure 11) a substantially greater amount of biomass is present in the 0-2 cm sediment depth interval, as well as a pocket of large biomass particles in the 5-10 cm interval. South Bellingham Bay biomass distribution (Figure 12) resembles the Devils Head conditions, except that the small amount of biomass in the uppermost sediment level is found in the 2.00 cm size category. The northern Bellingham Bay stations (Figure 13) have the most distinctive biomass distribution in this data set. Appreciable biomass occurs in the upper 5 cm of the sediment column in the 2.00 and 3.35 mm size categories, and the prominent biomass peak below 10 cm sediment depth in the 6.35 mm size category is lacking.

Benthic Community Structure

34. Substantial qualitative differences in the taxonomic composition and size distributions of benthos were readily apparent among the three study areas investigated (P. Striplin, personal communication). These differences are particularly notable in the 0-5 and 0-10 cm cumulative sediment depth fractions, which are important to the predator foraging groups described below. Benthic communities in the northern Puget Sound Bellingham Bay study area were dominated by bivalve molluscs (primarily *Axinopsida serricata*, with lower densities of *Macoma* sp.). Biomass represented by these species was largely concentrated in the upper 5 cm of the sediment column. Occassional occurences of large individual bivalves (e.g., *Clinocardium nuttallii* and *Compsomyax subdiaphana*) were documented in both north and south Puget Sound at sediment depths between 10 and 15 cm. Bivalves were the dominant taxon within the upper 5 cm of sediments in all strata within

the Bellingham Bay study area. Polychaetes were secondary biomass dominants at this depth, largely represented by terebellids (e.g., Tharyx sp.), maldanids, onuphids (e.g., Owenia fusiformis), and chaetopterids (e.g., Spiochaetopterus sp.). Benthic size distributions within the northeastern third of the southern Bellingham Bay ZSF and virtually all of the northern ZSF exhibited a mode of 2 mm within the 0-5 and 0-10 cm cumulative sediment depth fractions. Modal sizes shifted toward larger infaunal polychaetes for stations to the south and southwest, where the mode was 3.35 mm for the 0-5 cm sediment depth interval and 6.35 mm for the 0-10 cm interval. The only additional taxon of consequence in terms of biomass contributions was the occasional occurrence of the large burrowing anemone, Pachycerianthus sp..

35. In southern Puget Sound some qualitative differences in infaunal size distribution patterns were demonstrated between Anderson Island/Ketron Island (ZSF 2) and Anderson Island/Devils Head (ZSF 3). At both locations at sediment depths of 5 cm or greater, polychaetes were the dominant taxon in almost all defined strata. A few exceptions occurred where burrowing anemones were found at both sites. Ostracods (Euphilomedes producta and E. charodonta) dominated biomass contributions to strata A2 and B1 in the 1.00 mm size mode at both sites. Ostracods were secondary dominants in the remaining strata. Other crustaceans such as amphipods and cumaceans (e.g., Eudorella pacifica and Eudorellopsis sp.) contributed to the large crustacean biomass located in the upper 2 cm of the sediment column. These taxa were found to be fairly important constituents of the diets of several target fish species in the study area. Other crustaceans of note were mysids and euphausiids, which are considered to be facultative epibenthos/zooplankton. These were dominant taxa within the 0-2 cm sediment depth fraction at two stations (stratum B2) in the Anderson Island/Devils Head study area, and were found in the stomach contents of several fish samples. Polychaete modal size categories were 3.35 and 6.35 mm at 5 cm or greater sediment depths. High densities of small (i.e. 1.00 mm size mode) polychaetes, predominantly Tharyx sp., were common at both of the southern Puget Sound study areas. Ophiuroids (primarily Ophiodia sp.) were a particularly important benthic taxon at the Anderson Island/Devils Head site. These brittle stars displayed size modes of 2.00 to 6.35 mm, and were found primarily at or below a sediment depth of 5 cm. As reported below, ophiuroids were documented to be important food items of English sole feeding at this location. Benthic infaunal biomass distributions at both of the southern Puget Sound study areas were found to be bimodal due to the presence of small (1.00 mm) crustaceans (e.g., ostracods, cumaceans and amphipods) and polychaetes (e.g., juvenile Tharyx sp.), and larger (3.35-6.35 mm) polychaetes (e.g, maldanids, terebellids and opheliids), bivalves, and ophiuroids within the 0-5 and 0-10 cm sediment depth fractions. Feeding habits of demersal fishes in both study areas reflected the observed size distributions of the infaunal assemblages present.

Fish Food Habits Samples

Field Observations

36. A total of 41 species-size class samples (meeting an arbitrary criterion of at least two stomachs containing identifiable material per sample) were used in the analysis. Additional species were represented in the trawl catch, but not in sufficient numbers in a given size class to justify inclusion. Among these 41 species-size classes a total of 502

individual stomachs was distributed (Table 2). Sample size was unequal among species and study areas, generally reflecting the composition of the catch at the respective study areas. English sole made up the majority of the total catch, and was the most abundant target species at both Anderson Island study areas. At Bellingham Bay, snake prickleback were taken in high numbers, in addition to English sole, butter sole, and starry flounder. Rock sole were taken in sufficient numbers to form an adequate sample at Anderson Island/Devils Head only. Dover sole and rex sole were taken only at Anderson Island/Ketron Island. The catch differs substantially from that taken in a previous investigation of proposed Puget Sound disposal sites in Commencement Bay, Elliott Bay, Port Gardner, and Saratoga Passage (Clarke, 1986). At these sites the catch was more evenly distributed among slender sole (Lyopsetta exilis), Dover sole (Microstomus pacificus), and English sole (Parophrys vetulus), and smaller numbers of flathead sole (Hippoglossoides elassodon) and rex sole (Glyptocephalus zachirus). The size distributions of English sole in the present study differed somewhat among study areas. For example, the size mode of English sole at Anderson Island/Ketron Island fell into the 20-24.9 cm SL category, whereas at Anderson Island/Devils Head the majority of individuals were in the 15-19.9 cm SL size category. English sole larger than 30 cm SL were taken only at the Anderson Island study areas, whereas individuals smaller than 15 cm SL were taken only in Bellingham Bay. These observations generally support the concept that juvenile English sole prefer shallower habitats than adults, and that Bellingham Bay may serve as an important nursery area for this species.

37. Despite the fairly deep water depths along some of the trawl transects, the general condition of the stomach contents was excellent, as indicated by the low biomass percentages (never exceeding 16.7%) of unidentifiable food items.

Species Accounts - Taxonomic Composition of the Diets

38. The food habits data for each target predator species are discussed below. Recognition should be given to the fact that sample size for several target species is limited, and to the single season coverage of the samples. Thus the results reflect a "snapshot" of the feeding behavior of these species, and not a comprehensive picture of their biology. Figure 23 displays the taxonomic composition of the diets on a percent biomass basis. Morphological features, particularly of the mouth and dentition, are important considerations in the selection of target species for the ensuing analysis. Detailed descriptions of the morphology of target species treated below are given in Hart (1973).

(a) English Sole (Parophrys vetulus) - This species displays the classic morphological features of an infaunal-feeding flatfish. The terminally placed mouth is asymmetrical, facilitating downward orientation during feeding, and has a small gape. Composition of the diet of juvenile English sole varied among sites and habitats sampled by Simenstad et al. (1979). Important prey items in mud/eelgrass and sand/eelgrass habitats included cumaceans, gammarid amphipods, polychaetes, tanaids, crabs, and bivalves. A number of additional studies have reported the food habits of this flatfish (Kravitz et al., 1976; Hulberg and Oliver, 1979; Becker, 1984a,b; Cross et al., 1985; Becker and Chew, 1987). Notable food items include bivalve siphons, polychaetes, small crabs and shrimps, and brittle stars. Samples collected by Becker (1984a) in central Puget Sound had diets consisting mainly of polychaetes (over 70 percent by abundance), molluscs (about 18 percent), and crustaceans (about 10 percent). Becker's (1984b) samples from the Commencement Bay area had eaten primarily polychaetes (84.4 percent relative abundance) and molluscs (14.0 percent). English sole in the Commencement Bay area were shown to selectively prey on Capitella spp. in bottom habitats disturbed by releases of municipal sewage effluent (Becker and Chew, 1987). Abundance of English sole was demonstrated by Cross et al. (1985) to be correlated positively with increasing polychaete density along a pollution gradient on the continental shelf off Los Angeles, California. Overall these fish had a diet consisting of polychaetes, nematodes, bivalves, gastropods, and small crustacea. For English sole collected in Commencement Bay and Port Gardner, Clarke (1986) reported that the diet consisted largely of polychaetes and bivalves. In the present study samples of English sole fed primarily on some combination of polychaetes, bivalve molluscs, euphausiids (note that mysids were pooled with this taxon), amphipods, decapods (generally small crabs and shrimp), and ophiuroids, with other taxa such as ostracods and cumaceans contributing significantly to several food habits samples. Euphausiids/mysids were an important food item at the Anderson Island/Devils Head study area in particular. Their contribution diminished somewhat at Anderson Island/Ketron Island, and became negligable at Bellingham Bay. This corresponds dramatically with the abundances of euphausiids/mysids in the trawl catches at these sites. Cumaceans represented a notable percentage of the diet of Englsh sole samples from Anderson Island/Ketron Island only. In contrast, ophiuroids were essentially absent from English sole taken from Anderson Island/Ketron Island. This pattern is reversed for Anderson Island/Devils Head English sole samples which contained ophiuroids but not cumaceans.

(b) Dover Sole (Microstomus pacificus) - Dover sole are also an excellent example of an infaunal-feeding flatfish. In a study by Pearcy and Hancock (1978), Dover sole fed predominantly on annelids (64.4 percent by weight) and secondarily on molluscs (18.3 percent) and crustaceans (11.2 percent). They reported that Dover sole were opportunistic feeders, as the diet varied with sediment type. Their catch of Dover sole on the Oregon coast was positively correlated with the abundance of polychaetes in grab samples. In a study of resource partitioning among a guild of flatfishes in central Puget Sound, Becker (1984a) observed that Dover sole preferred deeper (32 m), muddy nearshore habitats, and were primarily diurnal feeders. Polychaetes were a major food item (approximately 58 percent by abundance), followed by crustaceans and molluscs (approximately 30 and 13 percent respectively). In a separate study of flatfishes taken from the delta of the Puyallup River in lower Commencement Bay, Becker (1984b) reported that Dover sole diets consisted of 63.1 percent (relative abundance) annelids, 22.5 percent crustaceans, and 14.4 percent molluscs. Although less selective than English sole or rex sole, Dover sole were found to be capable of effective predation on Capitella spp. by Becker and Chew (1987). The abundance of Dover sole increased along a pollution gradient created by effects of municipal wastewater effluent near Los Angeles, California (Cross et al., 1985). In a manner similar to that reported by Pearcy and Hancock (1978), the abundance of Dover sole paralleled the increasing abundance of polychaetes in the sediments along the gradient. This was reflected in their diets as polychaetes became more important prey components. Crustacea showed an opposite trend of decreasing abundance along the gradient, both in the grab samples and in the stomach contents samples. Gabriel (1981) investigated factors determining feeding selectivity by Dover sole on the Oregon continental shelf. She noted that polychaetes and ophiuroids were more important prey items in terms of weight, numbers, and frequency of occurrence than molluscs or crustaceans. Clarke (1986) reported that Dover sole fed largely on annelids. Bivalves were also important, particularly for larger size classes (25-29.9 and 30-34.9 cm SL) at the Port Gardner Alternative Disposal Site. A single size class sample (25-29.9 cm SL) at the Commencement Bay Alternative Disposal Site had eaten decapods almost exclusively. Dover sole taken from the Elliott Bay Alternative Disposal Site exhibited comparatively high diversity of stomach contents, including mysids, amphipods, cumaceans, isopods, and ostracods in appreciable amounts. In the present study, the single Dover sole size class sample, collected at Anderson Island/Ketron Island, fed on polychaetes and anemones, with additional minor prey contributions of amphipods, decapods, and euphausiids/mysids.

(c) Rex Sole (Glyptocephalus zachirus) - The rex sole is another small-mouthed flatfish. Pearcy and Hancock (1978) reported that rex sole smaller than 15 cm SL fed primarily on amphipods and other crustaceans, whereas larger rex sole shifted their diets to mainly polychaetes. In the Gulf of Alaska rex sole (12-26 cm) were found by Smith et al. (1978) to eat mainly polychaetes (54.6 percent by weight), followed by pandalid shrimp, small crabs, euphausiids, and pelecypods. Rex sole collected in central Puget Sound by Becker (1984a) had stomach contents consisting almost entirely of polychaetes. His samples contained fish in the 21-29 cm Total Length (TL) size range. At Commencement Bay, Becker (1984b) determined that rex sole had also eaten primarily polychaetes (over 96 percent relative abundance). Rex sole (5-9.9 cm SL) taken from Elliott Bay had eaten decapods, copepods, and amphipods (Clarke, 1986). In the present study, rex sole were taken only at the Anderson Island/Ketron Island study site. Three rex sole captured in trawls in the northern section of ZSF 2 had eaten primarily bivalves and decapods, whereas the diet of eight fish from the southern portion of the ZSF consisted largely of polychaetes.

(d) Rock sole (Lepidopsetta bilineata) - Rock sole fit the general morphological pattern of a bottom-feeding flatfish. The mouth is small, terminal in position, and has a small gape. The asymmetrical jaws have a slight upward orientation. As summarized by Hart (1973) and Livingston and Goiney (1983), the diet of this species as documented in past studies consists of mollusc siphons, small clams, polychaetes, shrimps, small crabs, amphipods, brittle stars, and sand lance. On the basis of sixty-six rock sole stomachs taken in northern Puget Sound Simenstad et al. (1979) reported that polychaetes, tanaids, gammarid amphipods, bivalves, and caridean shrimp were important food items. The single species size class sample taken in the present study (from Anderson Island/Devils Head) had eaten primarily cerianthid anemones, with smaller biomass contributions of bivalves and polychaetes.

(e) Butter sole (Iopsetta isolepis) - This species also possesses a small, asymmetrical, terminal mouth with a narrow gape. Descriptions of the diet of this flatfish from the literature (Livingston and Goiney, 1983) note that polychaetes, small bivalves (Macoma sp.), ophiuroids, shrimps, crabs, and fishes as prey items. Forrester (1969) reported polychaetes, clams, small crabs, and sand lance in butter sole from British Columbian waters. In the present study this target species was captured in sufficient numbers only in Bellingham Bay. These butter sole had eaten predominantly a mix of polychaetes and small bivalves, with amphipods and ophiuroids present in smaller quantities.

(f) Starry flounder (Platichthys stellatus) - This flatfish is similarly characterized by a small, terminal mouth with a narrow gape. The mouth is asymmetrical, facilitating feeding on and in the bottom. The diet of starry flounder in northern Puget Sound shallow sublittoral habitats has been described by Simenstad et al. (1979) as consisting mainly of polychaetes, amphipods, tanaids, bivalves, cumaceans, and mysidaceans. Orcutt (1950), Miller (1967) and Jewett and Feder (1980) have also reported on the diet of starry flounder. This species appears to modify its diet in accordance with the relative abundances of epifaunal and infaunal prey. Major prey items in the northern extent of its geographical range include brittle stars and protobranch clams (Jewett and Feder, 1980). Orcutt (1950) and Miller (1967) also reported that small bivalves were important food items of starry flounder from Monterey Bay, California, and the San Juan Archipelago, Washington respectively. This is consistent with the results of the present study. Three separate species size class samples taken at Bellingham Bay and representing eighteen fish had essentially identical stomach contents. Bivalves contributed ninety percent or greater of the dietary biomass in each sample.

(g) Snake prickleback (Lumpenus sagitta) - This is the only non-pleuronectid target species used in the present study. Although pricklebacks are demersal fishes, little is known of their food habits. As cited by Livingston and Goiney (1983), a study of forty-nine snake pricklebacks from Alaskan waters revealed a diet of polychaetes, gammarid amphipods, fish eggs, decapods, and small molluscs. Simenstad et al. (1979 reported that this species was primarily a benthic feeder in northern Puget Sound. Bivalves, tanaids, polychaetes, and gammarid amphipods were found to be impotant fodd items in terms of abundance and weight. A decision to sample this species in the present study was based on visual examination of their stomach contents from trawl catches in Bellingham Bay. The eighty-nine fish sampled had predominantly eaten polychaetes, bivalves, and amphipods, supplemented by smaller quantities of ophiuroids, ostracods, cumaceans, and decapods.

39. These data indicate that for the purposes of the BRAT analysis, all of the samples of target species described above are suitable for use in the overall evaluation due to their demonstrated reliance on infaunal prey items.

Fish Prey Size Feeding Strategies

40. The results of cluster analysis (see Appendix) and graphical treatment of the food habits biomass data were used to classify species and size classes into prey size feeding strategy groups that are described in Table 3. Figures 24 through 30 are displays of the prey size exploitation patterns of these feeding strategy groups. In sequence the figures show a gradual shift in prey size preference from small to large prey, with Group IIIB predators utilizing the larger prey size categories almost exclusively. Table 4 lists the fish species and size classes assigned to each group. Note that in a number of instances the same size class of the same fish species exhibits a different feeding strategy. For example, English sole

representing the 15-19.9 cm SL size class from the various study areas fall into Groups IIA, IIB, IID, and IIIA. Likewise, at least one English sole 20-24.9 cm SL size class sample is found in every feeding strategy group. Given the caveat that sample sizes are fairly small, this may be an indication that qualitative differences in the prey available to these bottom feeders exist at the various sites. Composition of several groups show a substantial degree of species integrity. For example, snake prickleback samples occur only in Group IIA, and starry flounder samples occur only in Group IIB. Although sample sizes are small, an ontogenetic shift in diet is apparent among butter sole samples. Butter sole in the 5-9.9 cm SL size category fall into Group IIB, which has a relatively small prey size mode. Group IID, with a somewhat larger prey size mode, contains 10-14.9 cm SL butter sole. Finally, the largest butter sole, in the 15-19.9 cm SL size category, show a Group IIIB feeding strategy, in which very large prey items are utilized.

41. Observed differences in prey size exploitation patterns by the same species and size class captured from two locations, however slight, lead to questions regarding feeding efficiency. Data on the weight of each fish food habits sample and the number of stomachs that comprised each pooled sample (given in Appendix) were used to calculate the mean weight of food in each sample (Table 5). These calculations indicate that although feeding efficiency was on the whole low (ie., small amounts of biomass per stomach), substantial differences in feeding efficiencies among the study areas are not apparent. Not surprisingly, a slight trend is shown for increasing mean biomass of stomach contents with increasing Standard Length. No striking differences are noted among study areas for English sole samples of the same size category.

Benthic Resource Value Analysis

Computation of Benthic Resource Value

42. Cumulative benthic biomass within the various sediment depth fractions for each benthic stratum forms the basic input into the resource value computations. These data are presented in Table 6. For each stratum a determination of that portion of the total benthic biomass that is both vulnerable and available to predation is made. Those portions of the total biomass determined to be either too small or too large to fit a predator group's feeding strategy (not vulnerable) or beyond that predator group's foraging depth (not available) are deleted from the appropriate stratum's total biomass. Recall that parcels of large bivalve biomass, which do not represent prey items, have already been removed from the data set.

43. Comparison of the taxonomic composition of the diets of fish size class samples in each predator feeding strategy group reveals that in several cases a group consists partially or mainly of epibenthic rather than infaunal feeders. Groups which contain no evidence of infaunal feeding are logically of little importance in assigning a value to the benthos as trophic support. For example, several samples of demersal fishes in Puget Sound were reported by Clarke (1986) to have fed predominantly on epifaunal organisms and were not considered in a trophic resource analysis. In the present data set, however, all samples of demersal fishes were demonstrated to have preyed heavily on infaunal prey items and are treated below.

44. First, an estimate is made of the size range of prey showing significant (i.e. for the purposes of the analysis a ten percent dietary contribution within a single prey size category has arbitrarily been defined as significant) exploitation by a given predator group. For example, from Figure 15, it can be seen that prey size categories between 1.00 and 2.00 mm contribute at least ten percent to the overall diet of Group IIA predators. Likewise, for Group IIB predators prey between 1.00 and 3.35 mm are major dietary contributors (Figure 16). In the case of Group IIA predators prey biomass in the appropriate benthic strata smaller than 1.00 mm and larger than 2.00 mm will be considered to be outside of the vulnerable range size. For Group IIB predators, prey smaller than 1.00 mm and larger than 3.35 mm will be considered outside of the vulnerable size range.

45. Next, a determination is made of the foraging depth of the selected predator groups. This is the most subjective step in the overall analysis, and requires extensive investigation of the data sets. For example, if polychaetes are the major prey taxon of a particular predator group, examination of the vertical distribution of polychaete biomass in the sediments at stations adjacent to the trawl transects from which the fish samples were captured can provide insight into the probable foraging depth of those fishes. If the major concentration of polychaete biomass lies between 2 and 5 cm, then a conclusion can be reached that the fishes are exploiting the 0-5 cm sediment depth fraction. If the polychaete biomass accumulates in a linear fashion with sediment depth down to 15 cm, then best available information on the feeding behavior of a given species must be relied upon. For example, Gabriel (1981) reported that only large size classes of Dover sole foraged deeper than 2 cm into the sediment. This approach, however, must consider the behavior of the specific prey items. Many species of polychaetes which build tubes deep into the sediment are surface deposit-feeders. Although fish are able to crop the exposed portions of the annelids at the sediment surface, the biomass for these polychaetes may actually be found quite deep in the box-corer samples. During sampling these and other annelids might be expected to retract downward into their tubes. Specific taxa may act as labels of distinct foraging depths. Based on considerations such as these, an estimated foraging depth for each predator group is reached.

46. The results of the benthic resource computations are presented in Tables 7 through 13. For Group IIA predators, which include several 15-20 cm SL size class samples of English sole and all three snake prickleback samples, a 5 cm foraging depth was used (Table 7). From the total biomass in the 0-5 cm sediment depth available zone, as depicted in Figure 22, that portion determined to be outside of the vulnerable range is removed. This operation is repeated for each 0-5 cm benthic stratum. The biomass remaining in each stratum is then a measure of the potential biomass that can be utilized by Group IIA predators at stations in that respective stratum. In establishing biomass criteria for the benthic strata, a progression from very low biomass in Stratum A1 to very high biomass in Stratum D1 was created. However, the resource analysis for Group IIA predators indicates that, for this group of predators, Stratum B1 (26.1 g/sq m) contained a greater potential food resource than Stratum D1 (12.0 g/sq m). An overall pattern of rough equivalence of potential food value among strata existed, with the exception of the peak biomass in Stratum C1. The total potential food biomass available to predators selecting mainly small prey items is, however, shown to be relatively low in comparison with that

available to predators feeding on larger infaunal prey items.

47. Group IIB predators included two 15-20 cm SL size class samples of English sole, all three samples of starry flounder, and the smallest size class sample (5-10 cm SL) of butter sole. This group was also assigned a 0-5 cm foraging depth (Table 8). Group IIB predators show a nearly identical distribution of potential food biomass as do the Group IIA predators (Figure 24). Benthic strata A1, B1, B2, and D1 afforded roughly equivalent amounts of potential food biomass to Group IIB predators, with a significant food biomass peak in Stratum C1. In each stratum the potential food biomasses were slightly higher for Group IIB predators than for Group IIA.

48. Group IIC predators, representing two 20-25 cm SL size class samples of English sole from Anderson Island/Ketron Island, were assigned to 0-10 cm foraging depth (Table 9). This group showed the highest potential trophic support values for each benthic stratum. This is probably accounted for by the comparatively high benthic biomasses in the upper 10 cm of the sediment column at Anderson Island/Ketron Island in the appropriate size range. A clear sequence of increasing potential food biomass is seen in the series of values for Strata A1 through D1. The Stratum D1 potential food biomass value (115.4 g/sq m) for this predator group was the highest value recorded in the present study.

49. Group IID predators, represented by eleven English sole size class samples and single rex sole (15-20 cm SL) and butter sole (10-15 cm SL) samples, were assigned a 0-10 cm foraging depth (Table 10). All but two of the English sole samples were from the Anderson Island/Devils Head study area. Benthic strata provided intermediate amounts of potential food biomass to this group. Potential food biomass peaked in Stratum C1 (49.3 g/sq m, Figure 24), and declined in Strata C2 and D1.

50. Group IIE and IIIA predators were assigned a 0-10 cm foraging depth (Tables 11 and 12). Because their respective prey size utilization patterns were both in the 2.00 to 6.35 mm range, the trophic resource analysis values are identical for both groups. The shift to larger prey sizes becomes apparent in the pattern of increasing food biomass following the Stratum A1 to D1 sequence. The abundance of large prey items in Stratum D1 within the upper 10 cm of the sediment column determines the observed distribution of food resource.

51. Group IIIB predators, comprised of three samples of larger English sole and a single sample of large (15-20 cm SL) butter sole, also were assigned a 0-10 cm cm foraging depth (Table 13). A pattern of increasing potential food biomass through the Stratum A1 to Stratum D1 sequence was generally seen, with a slight reduction noted for Stratum C1.

52. Figure 24 summarizes the estimates of trophic support potential for each benthic biomass stratum across predator feeding groups. The pattern that emerges is complex, with a number of deviations from a general trend for increasing trophic support with increasing total benthic biomass. Stratum A1 provides minimal trophic support for any feeding group. Groups IIA, IIB, and IID derive maximal potential trophic support from Stratum C1, whereas Groups IIC, IIE, IIIA, and IIIB are primarily benefited by Stratum D1.

CONCLUSIONS

53. A fundamental question faced by resource managers in the PSSDA Program is, "What open-water dredged material disposal plan is optimal with regard to logistical, economic, and environmental considerations?" Sampling effort in the present study was directed at providing insight into the environmental realm of this complex question. The study addresses the more specific question, "What are the comparative benthic habitat qualities of the proposed disposal sites in terms of potential trophic support for bottom-feeding fishes?"

54. An initial statement of the limits of the data is required. Because the data represent a single summer sampling effort, extrapolation of the results to a complete seasonal cycle is impossible. However, the data do adequately describe conditions at the project sites during a period when benthos are actively being exploited by resident fish populations. A second limitation of the data is that sampling effort was unequal among study areas such that not all target species were sampled at each site. This reflects in part variation in the habitat preferences of the selected target species. The ichthyofauna inhabiting the southern versus the northern Puget Sound study areas were not surprisingly quite different. Sufficient data were obtained to reach conclusions regarding key target species, particularly English sole.

55. The most remarkable difference between study areas observed in the data is the contrast inabundance of small bivalve molluscs. The dense standing crop of bivalves at Bellingham Bay provides an important food resource for several of the demersal fish species present. Starry flounder were found to be feeding almost exclusively on these small bivalves. Seasonal sampling would be necessary to determine whether other components of the benthos became more impotant as bivalve abundances varied, or whether bivalve production was sufficiently high to accomodate high levels of predation throughout the year.

56. The overall patterns of biomass distribution among size categories and vertical sediment depth fractions were essentially similar among study areas with the possible exception of the northern Bellingham Bay study area. Each site shows a predominance of large benthos found deep in the sediment column. This general condition is indicative of stable benthic communities in which larger, deeper-dwelling fauna have become established. The northern Bellingham Bay study area shows the largest departure from this pattern, although deep-dwelling fauna were indeed present. This may represent a north-south gradient in terms of benthic "quality" in response to altered conditions of physical stress (e.g., susceptibility to storm-induced disturbance) or perhaps anthropogenic perturbation (e.g., organic enrichment due to proximity to urban center). Other more subtle differences in the benthic assemblages at each study area relate to differences in potential trophic support. For example, the relatively higher biomasses of benthos in the upper sediment column at Anderson Island/Ketron Island as compared to Anderson Island/Devils Head accounts for higher calculated food resource values for benthic strata found primarily at the former site.

57. In summary, although major differences in benthic habitat quality were not demonstrated among the various study sites, observed patterns of

potential trophic resources available to demersal bottom-feeding fishes would support certain management decisions. At the Anderson Island/Devils Head study area low benthic biomasses were found in the upper sediment depth fractions to the north of the existing ZSF 3 boundaries. Location of the operational disposal site in the northern portion of ZSF 3, or shifting the disposal site boundaries northward of their present location would have the effect of minimizing detrimental impacts to the foraging base. At Anderson Island/Ketron Island stations characterized by low food resource value were generally located along the eastern edge of the ZSF 2 boundary. Placement of the operational disposal site in the eastern portion of ZSF 2 would appear to offer minimal risk to the existing trophic resource. At Bellingham Bay the northern ZSF appears to have somewhat higher trophic support value than the southern ZSF. In the southern Bellingham Bay study area an east-west gradient of increasing trophic resource value is indicated. Shifting the operational disposal site location slightly to the west would appear to be the best available option to minimize risk to the forage base.

EXECUTIVE SUMMARY

58. A Benthic Resources Assessment Technique evaluation of proposed open-water dredged material disposal sites in Puget Sound, Washington was performed. The evaluation, based on samples taken in July, 1987 at three study areas (Anderson Island/Devils Head, Anderson Island/Ketron Island, and Bellingham Bay), provides comparative assessments of benthic habitat quality at the study areas in terms of potential trophic support for bottom-feeding fishes. The results of this study are particularly relevant to utilization of the proposed sites by English sole and other small-mouthed flatfishes. Major findings of the study are outlined below.

A. Taxonomic composition (at the Class/Order level) of the benthos was found to vary subtly among the study areas. Polychaetes dominated the benthos at both of the southern Puget Sound study areas (ZSF 2 and ZSF 3), whereas bivalve molluscs became dominant at Bellingham Bay. Small crustaceans, especially ostracods, were more prevalent at the southern Puget Sound study areas.

B. With regard to total benthic biomass, the Anderson Island/Ketron Island study area was found to have the highest comparative standing crop of benthos, the Anderson Island/Devils Head area had the lowest standing crop, and the Bellingham Bay sites were intermediate. These differences were further emphasized with reference to vertical distributions. Anderson Island/Ketron Island had the highest available biomasses for the 0-2 cm sediment depth interval, but the northern Bellingham Bay site had the highest value for the 0-10 cm sediment depth interval.

C. Estimates of trophic support potential generally corresponded with total benthic biomass measurements at the various study sites. Size characteristics of potential prey played a secondary role in determining the trophic support provided by a given benthic stratum to a specific target fish feeding group. Station integrity, based on both biomass quantity and size characteristics, was high within each study area, indicating relatively homogeneous benthic assemblages at each area. Several gradients of food resource value, however, were found at individual sites.

59. Based on the results of the BRAT evaluation, it is the recommendation of the Coastal Ecology Group, WES that the observed patterns of trophic resource value for each study area be considered in the final selection of disposal site boundaries. Utilization of the benthic communities at each site appears to be sufficiently evidenced by the food habits investigation to justify shifting site boundaries slightly to optimize the available trophic support for resident and transient demersal fishes.

REFERENCES

Becker, D. S. 1984a. Resource partitioning by small-mouthed pleuronectids in Puget Sound, Washington. Ph.D. Dissertation, University of Washington, Seattle. 139pp.

Becker, D. S. 1984b. Implications of opportunistic predation for predicting ocean dumping impacts on demersal fishes. Paper presented at the International Ocean Disposal Symposium, September 10-14, 1984, Corvallis, OR.

Becker, D. S. and K. K. Chew. 1987. Predation on Capitella spp. by small-mouthed pleuronectids in Puget Sound, Washington. Fishery Bulletin. 85(3):471-479.

Borgeson, D.P. 1963. A rapid method for food habit studies. Trans. Amer. Fish. Soc. 92(4):434-435.

Carr, W.E.S. and C.A. Adams. 1973. Food habits of juvenile marine fishes occupying seagrass beds in the estuarine zone near Crystal River, Florida. Trans. Amer. Fish. Soc. 102:511-540.

Choat, J. H. 1982. Fish feeding and the structure of benthic communities in temperate waters. Annual Review of Ecology and Systematics. 13:423-449.

Clarke, D. G. 1986. Benthic resource assessment technique evaluation of disposal sites in Puget Sound and adjacent waters. Puget Sound Dredged Disposal Analysis Report. U.S. Army Corps of Engineers, Seattle District. 72pp.

Clarke, D. G. and J. D. Lunz. 1985. The Benthic Resources Assessment Technique in Theory and Practice. in Proceedings of the Environmental Review Conference, 1985, Atlanta, GA. Environmental Protection Agency.

Collie, J. S. 1987. Food selection by yellowtail flounder (Limanda ferruginea) on George's Bank. Canadian Journal of Fisheries and Aquatic Sciences. 44:357-367.

Cross, J. N., Roney, J. and G. S. Kleppel. 1985. Fish food habits along a pollution gradient. California Fish and Game. 71(1):28-39.

Forrester, C. R. and J. A. Thomson. 1969. Population studies on the rock sole, Lepidopsetta bilineata of northern Hecate Strait, B.C. Fisheries Research Board of Canada, Technical Report 108, 104pp.

Gabriel, W. L. 1981. Feeding selectivity of the Dover sole, Microstomus pacificus, off Oregon. Fishery Bulletin. 79:749-763.

Hagerman, F. B. 1952. The biology of Dover sole, Microstomus pacificus (Lockington), Fish Bulletin, California Department of Fish and Game, 85, 48pp.

Hart, J. L. 1973. Pacific Fishes of Canada. Fisheries Research Board of Canada. Bulletin 180, 740pp.

Hogue, E. W. and A. G. Carey. 1982. Feeding behavior of 0-age flatfishes at a nursery ground on the Oregon coast. Fishery Bulletin. 80:555-565.

Hulberg, L. W. and J. S. Oliver. 1979. Prey availability and the diets of two co-occurring flatfish. in Gutshop '78, Fish Food Habits Studies: Proceedings of the Second Pacific Northwest Technical Workshop. University of Washington, Seattle, WA. pp.29-36.

Jewett, S. C. and H. M. Feder. 1980. Autumn food of adult starry flounders, Platichthys stellatus, from the northeastern Bering Sea and the southeastern Chukchi Sea. Journal Conseil Internationale de la Mer. 39(1):7-14.

Kravitz, M. J., Pearcy, W. G. and M. P. Guin. 1976. Food of five species of co-occurring flatfishes on Oregon's continental shelf. Fishery Bulletin. 74:984-990.

Livingston, P. A. and B. J. Goiney. 1983. Food habits literature of north Pacific marine fishes: a review and selected bibliography. NOAA Technical Memorandum NMFS F/NWC-54, 81pp.

Lunz, J. D. and D. R. Kendall. 1982. Benthic Resources Assessment Technique, a method for quantifying the effects of benthic community changes on fish resources. in Proceedings of a Conference: Oceans '82, Washington, D.C. pp.1021-1027.

Miller, B. S. 1967. Stomach contents of adult starry flounder and sand sole in East Sound, Orcas Island, Washington. Journal of the Fisheries Research Board of Canada. 24:2515-2516.

Miller, B. S. 1970. Food of flathead sole (Hippoglossoides elassodon) in East Sound, Orcas Island, Washington. Journal of the Fisheries Research Board of Canada. 27:1661-1665.

Orcutt, H. G. 1950. The life history of the starry flounder, Platichthys stellatus (Pallas). Bulletin of the Department of Fish and Game, State of California. 78:1-64.

Pearcy, W. G. and D. Hancock. 1978. Feeding habits of Dover sole, Microstomus pacificus; rex sole, Glyptocephalus zachirus; slender sole, Lyopsetta exilis; and Pacific sanddab, Citharichthys sordidus, in a region of diverse sediments and bathymetry off Oregon. Fishery Bulletin. 76(3):641-651.

Rhoads, D.C., McCall, P.L. and J.Y. Yingst. 1978. Disturbance and production on the seafloor. American Scientist. 66:577-586.

Sheridan, P.F. 1979. Trophic resource utilization by three species of sciaenid fishes in a northwest Florida estuary. Northeast Gulf Sci. 3:1-5.

Simenstad, C.A., Miller, B.S., Nyblade, C.F., Thornburgh, K. and L.J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca: A synthesis of the available knowledge. Interagency Energy/Environment R&D Program Report. U.S. Environmental Protection Agency. EPA-600/7-79-259. 335pp.

Smith, R. L., Paulson, A. C. and J. R. Rose. 1978. Food and feeding relationships in the benthic and demersal fishes of the Gulf of Alaska and Bering Sea. in Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies. National Oceanic and Atmospheric Administration, Boulder, CO. 1:33-107.

Figure 1. Overview of study areas in Puget Sound, Washington. Anderson Island/Devils Head, Anderson Island/Ketron Island and Bellingham Bay are Phase II PSDDA study areas involved in the present study. Commencement Bay, Elliott Bay, Port Gardner and Saratoga Passage are Phase I study areas addressed in a previous study.

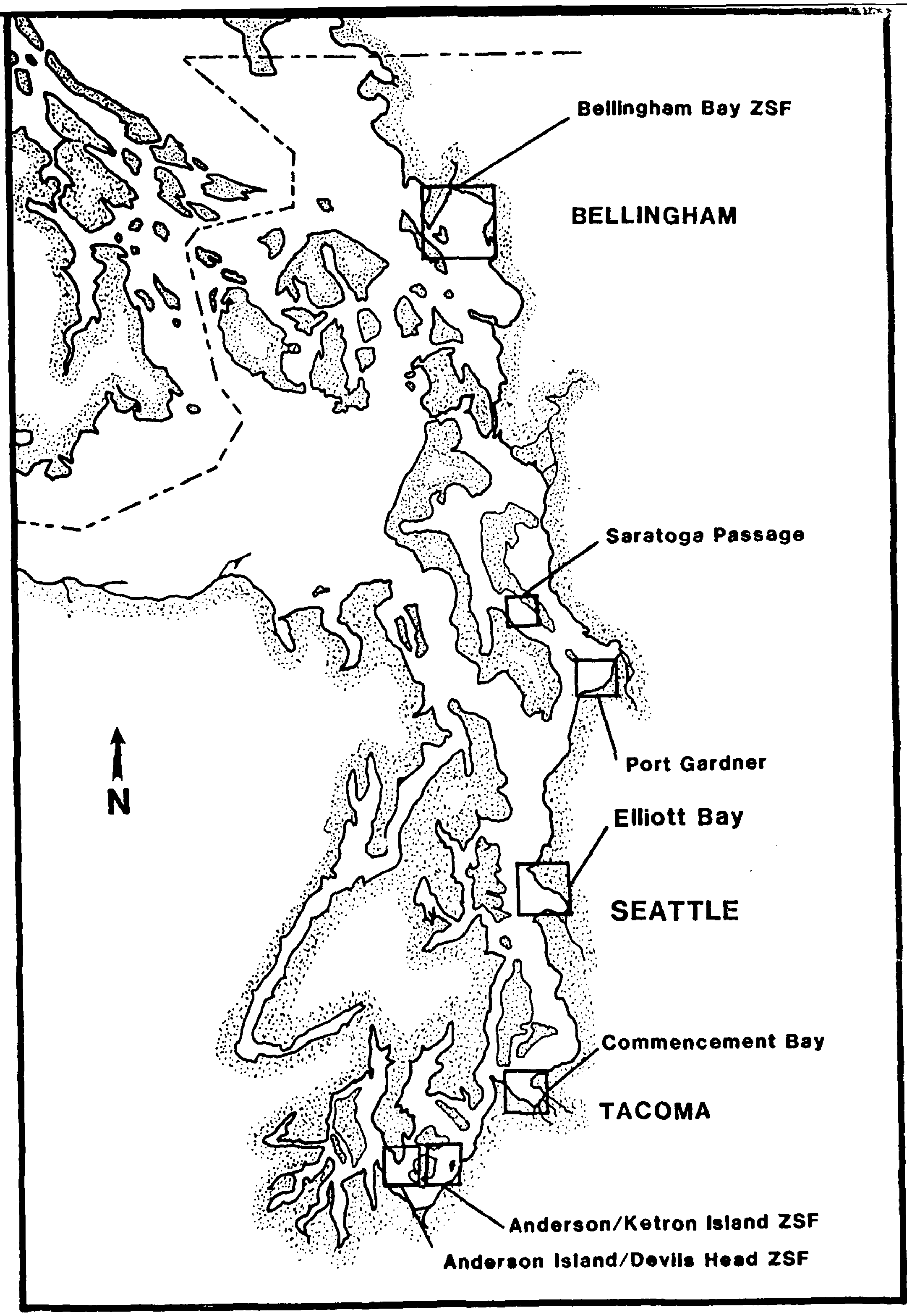

Bellingham Bay ZSF
BELLINGHAM
Saratoga Passage
Port Gardner
Elliott Bay
SEATTLE
Commencement Bay
TACOMA
Anderson/Ketron Island ZSF
Anderson Island/Devils Head ZSF
N

Figure 2. Sampling locations at Anderson Island/Devil's Head (ZSF 3) and Anderson Island/Ketron Island (ZSF 2). Approximate boundaries of the ZSF's are indicated by dashed lines with respective benthic (character/numeral) and trawl (T) stations noted. Reference stations denoted by R. Circled benthic stations indicate those locations at which box corer penetration problems were encountered.

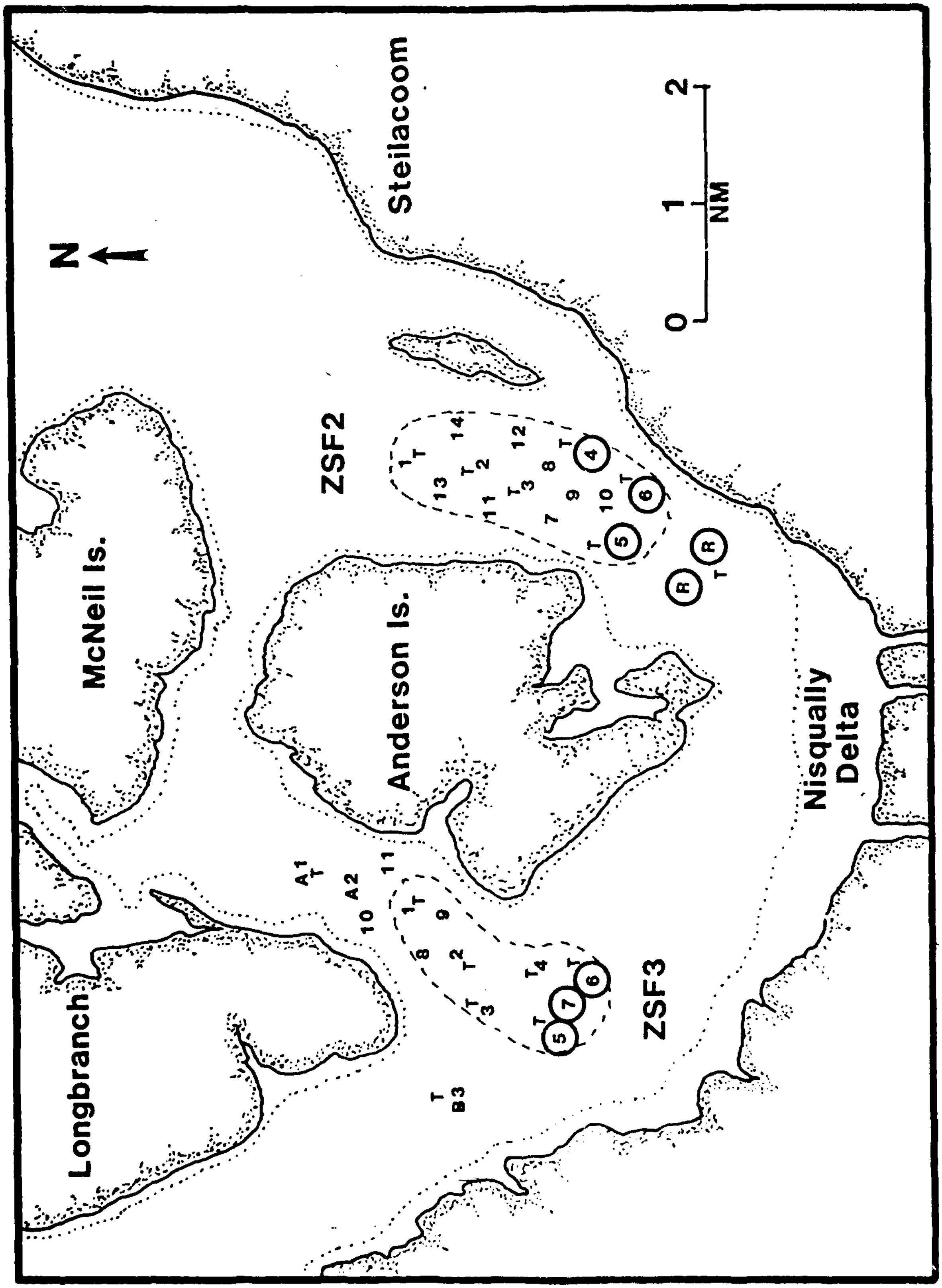
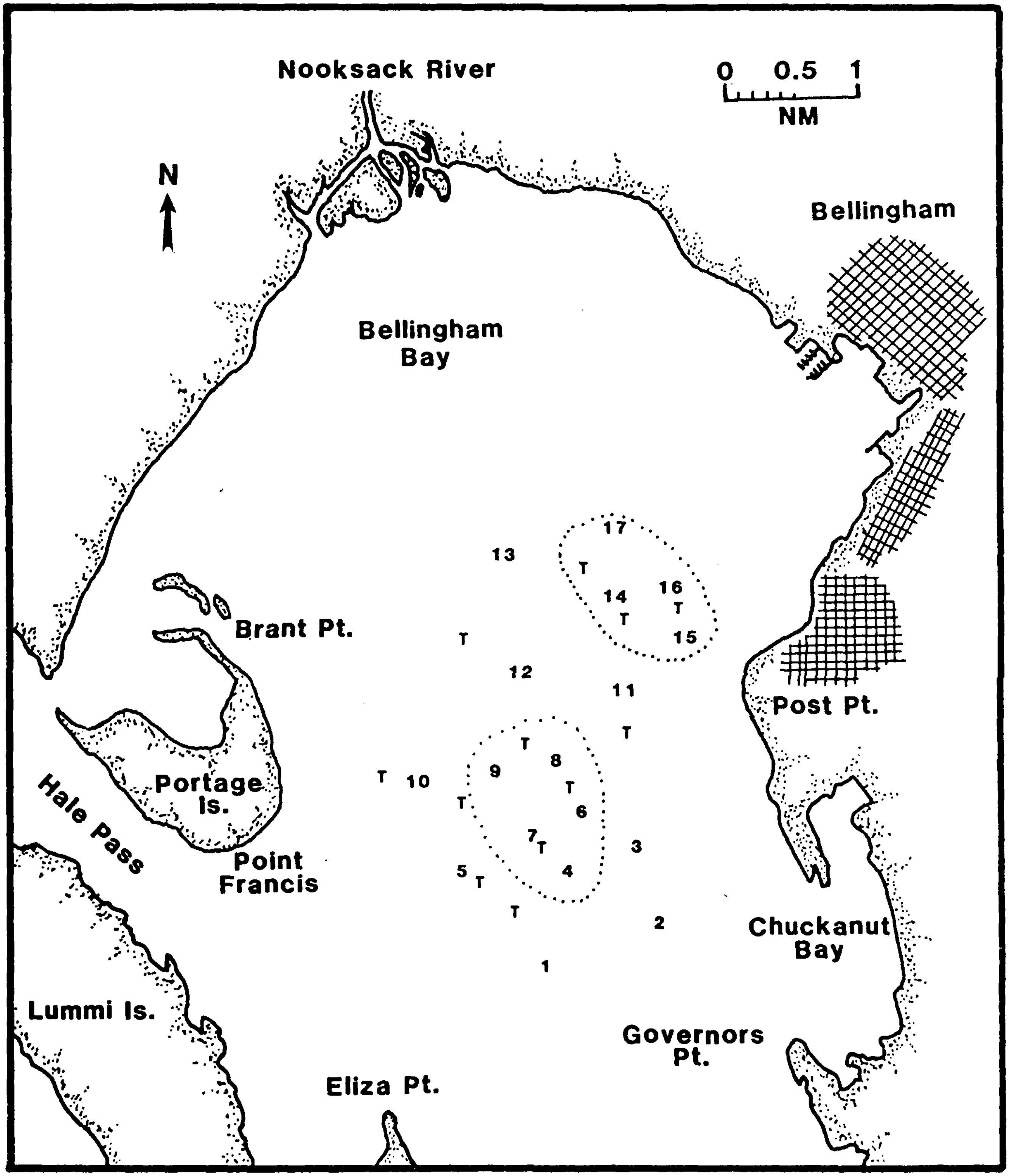
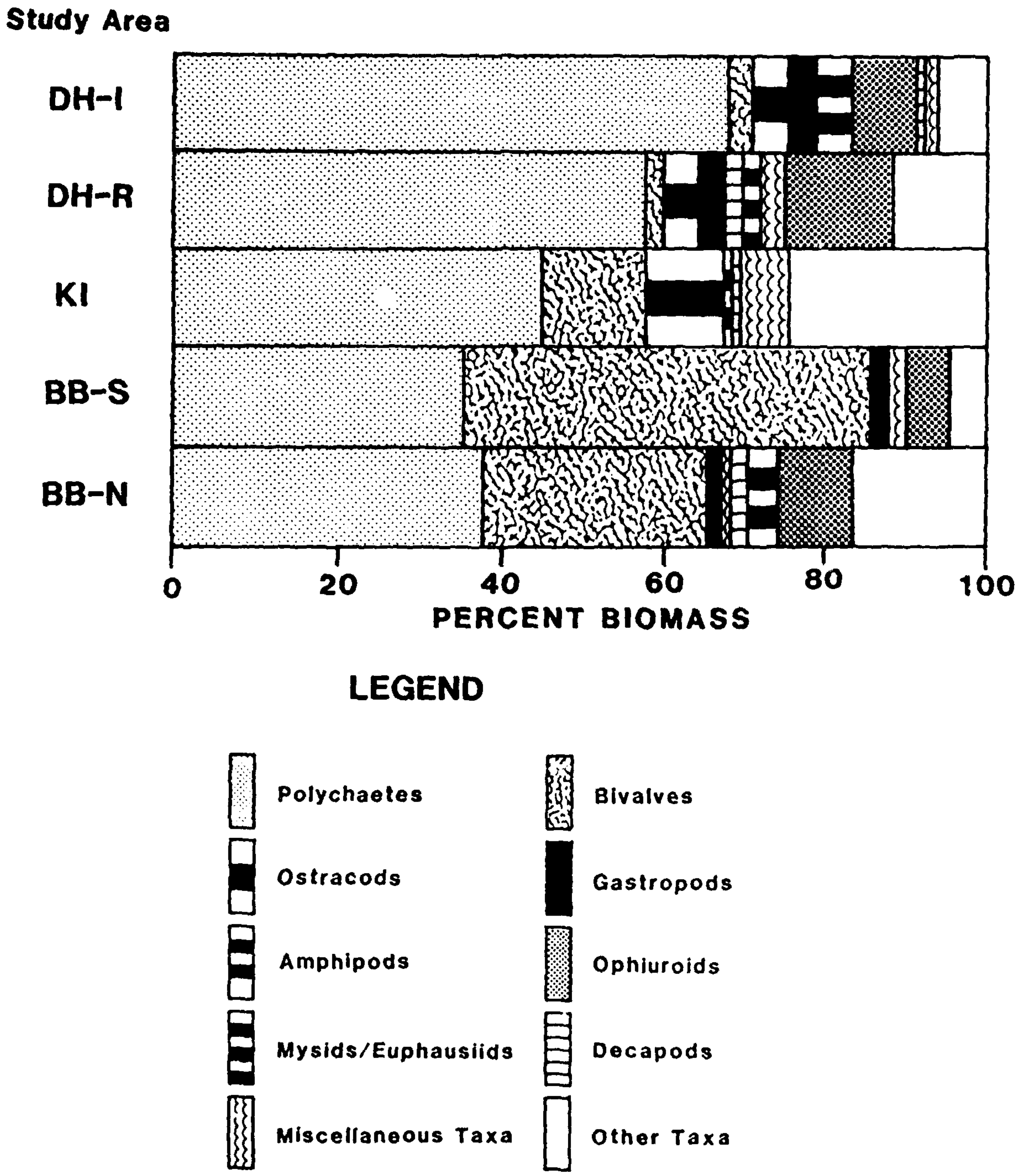

Steilacoom
McNeil Is.
Anderson Is.
Longbranch
Nisqually Delta
ZSF2
ZSF3
N
0
1
2
NM

Figure 3. Sampling locations at Bellingham Bay, Washington. Approximate boundaries of ZSF's indicated by dashed lines with respective benthic (numeral) and trawl (T) stations noted.



Nooksack River
0 0.5 1
NM
N
Bellingham
Bellingham
Bay
17
13
T
14
16
T
T
Brant Pt.
T
15
12
11
Post Pt.
T
T
8
9
T
T
10
Portage
Is.
T
6
Hale Pass
7
T
3
Point
Francis
5
T
4
T
2
Chuckanut
Bay
1
Lummi Is.
Governors
Pt.
Eliza Pt.

Figure 4. Taxonomic composition of benthos (large bivalves excluded) among the Puget Sound study areas. DH = Anderson Island/Devils Head (ZSF 3), KI = Anderson Island/Ketron Island (ZSF 2), BB = Bellingham Bay, I = Impact Area, R = Reference Area, S = South, N = North



Study Area
DH-I
DH-R
KI
BB-S
BB-N
0
20
40
60
80
100
PERCENT BIOMASS
LEGEND
Polychaetes
Bivalves
Ostracods
Gastropods
Amphipods
Ophiuroids
Mysids/Euphausiids
Decapods
Miscellaneous Taxa
Other Taxa

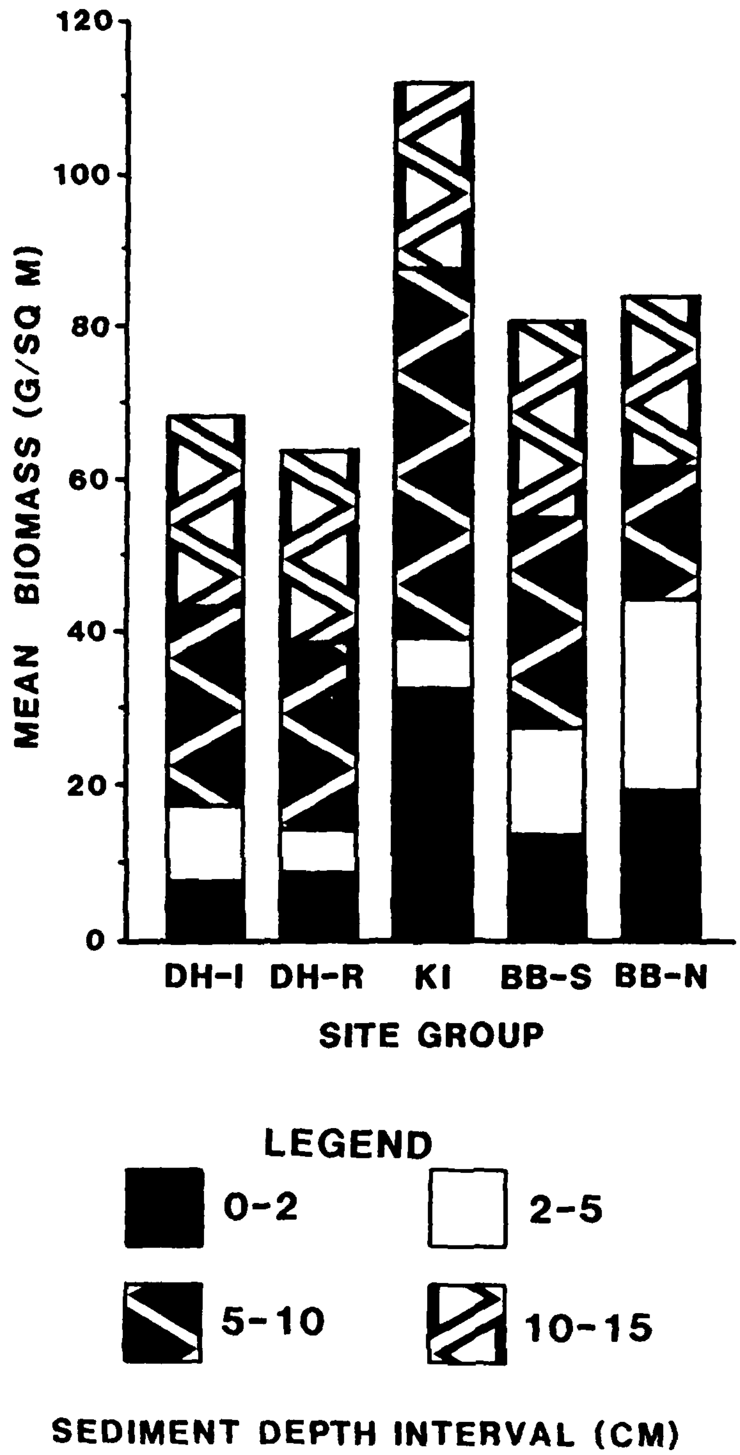
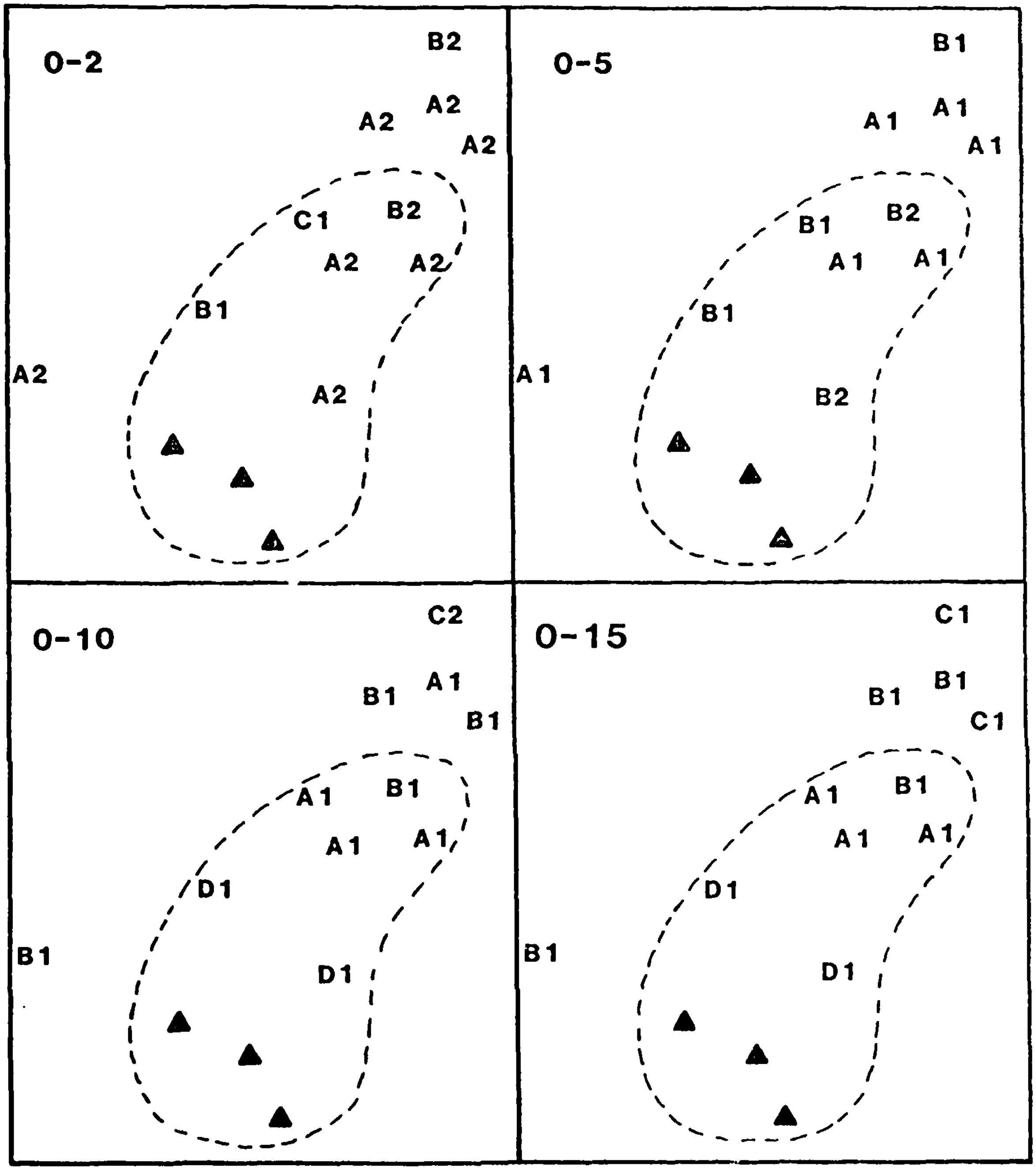


Figure 5. Distribution of mean benthic biomass among stations at each Puget Sound study area. DH = Anderson Island/Devil's Head, KI = Anderson Island/Ketron Island, BB = Bellingham Bay, I = Impact Area, R = Reference Area, S = South Area, N = North Area.



ANDERSON ISLAND/DEVILS HEAD

Figure 6. Benthic biomass strata at the Anderson Island/Devils Head (ZSF 3) study area. Strata A1, B1, and B2 are indicative of low biomass concentrations, whereas Strata C1 and D1 are indicative of high biomass concentrations. Solid triangles indicate stations relocated due to box corer penetration problems.

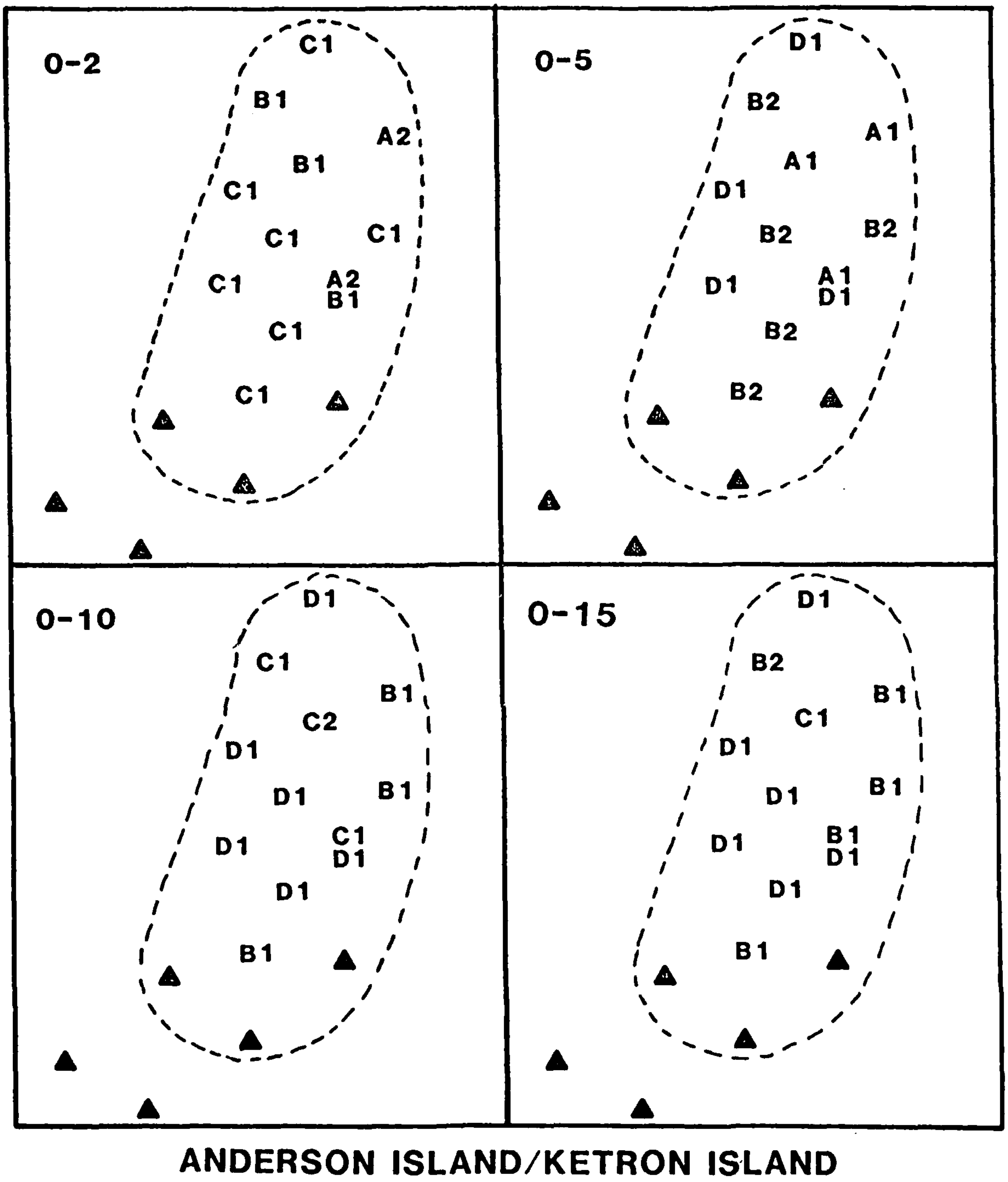


Figure 7. Benthic biomass strata at the Anderson Island/Ketron Island study area. Strata A1, A2, B1, and B2 are indicative of low biomass concentrations, whereas strata C1, C2, and D1 are indicative of high biomass concentrations. Solid triangles represent stations relocated due to box corer penetration problems.

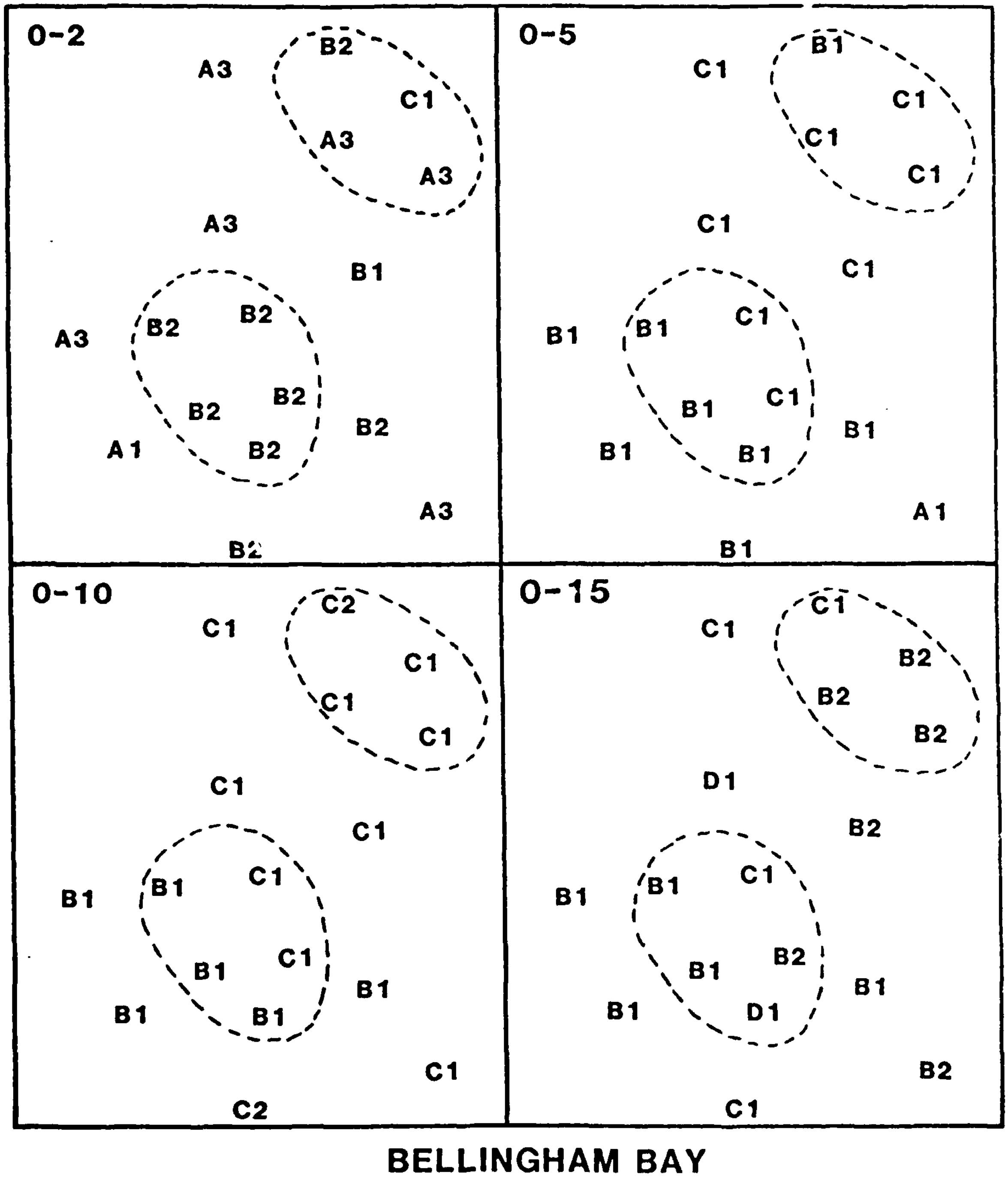


Figure 8. Benthic biomass strata at the Bellingham Bay study areas. Strata A1, A3, B1, and B2 are indicative of low biomass concentrations, whereas strata C1, C2, and D1 are indicative of high biomass concentrations.

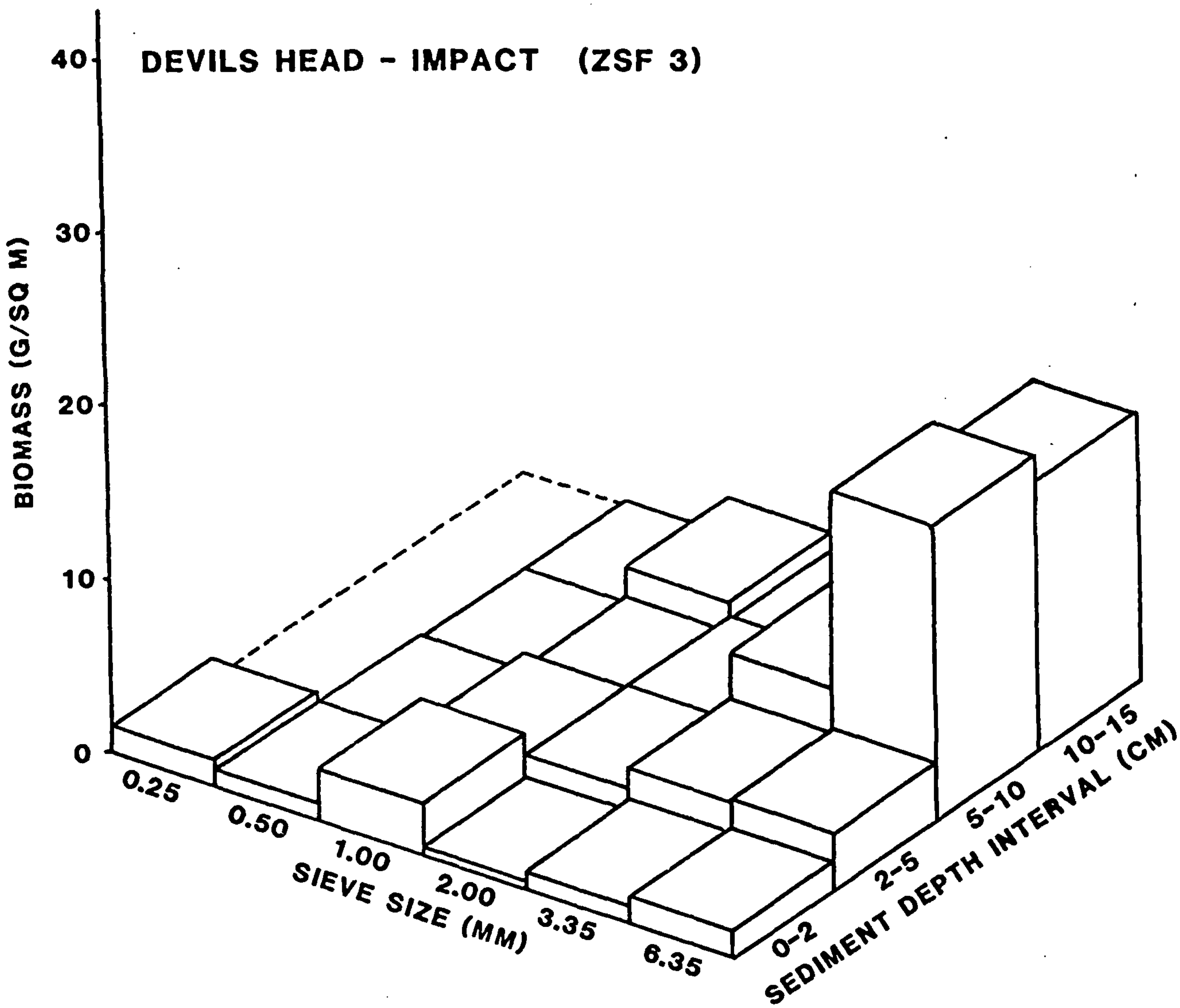


Figure 9. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Anderson Island/Devils Head (ZSF 3) impact study area.

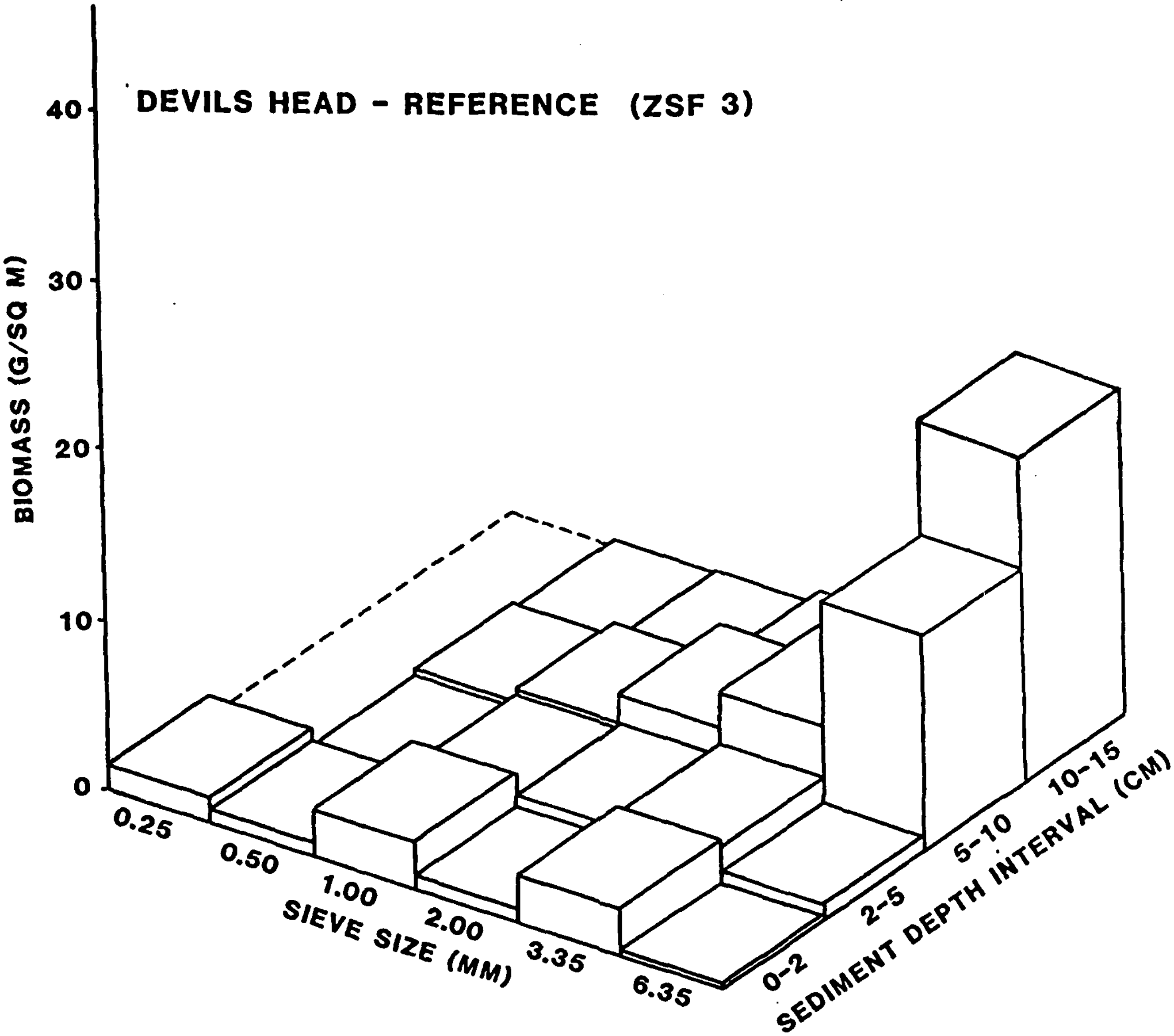


Figure 10. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Anderson Island/Devils Head (ZSF 3) reference study area.

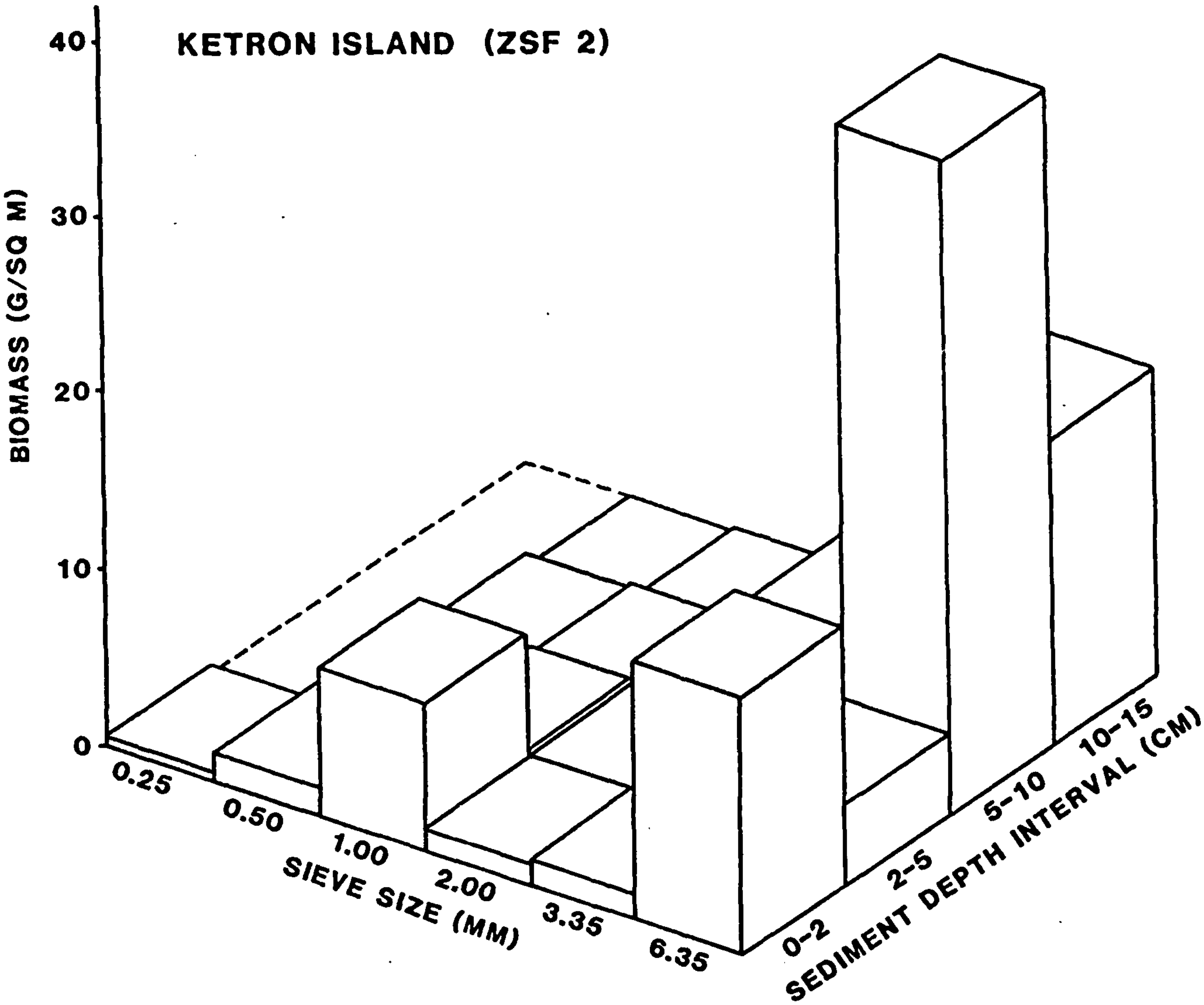


Figure 11. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Anderson Island/Ketron Island study area.

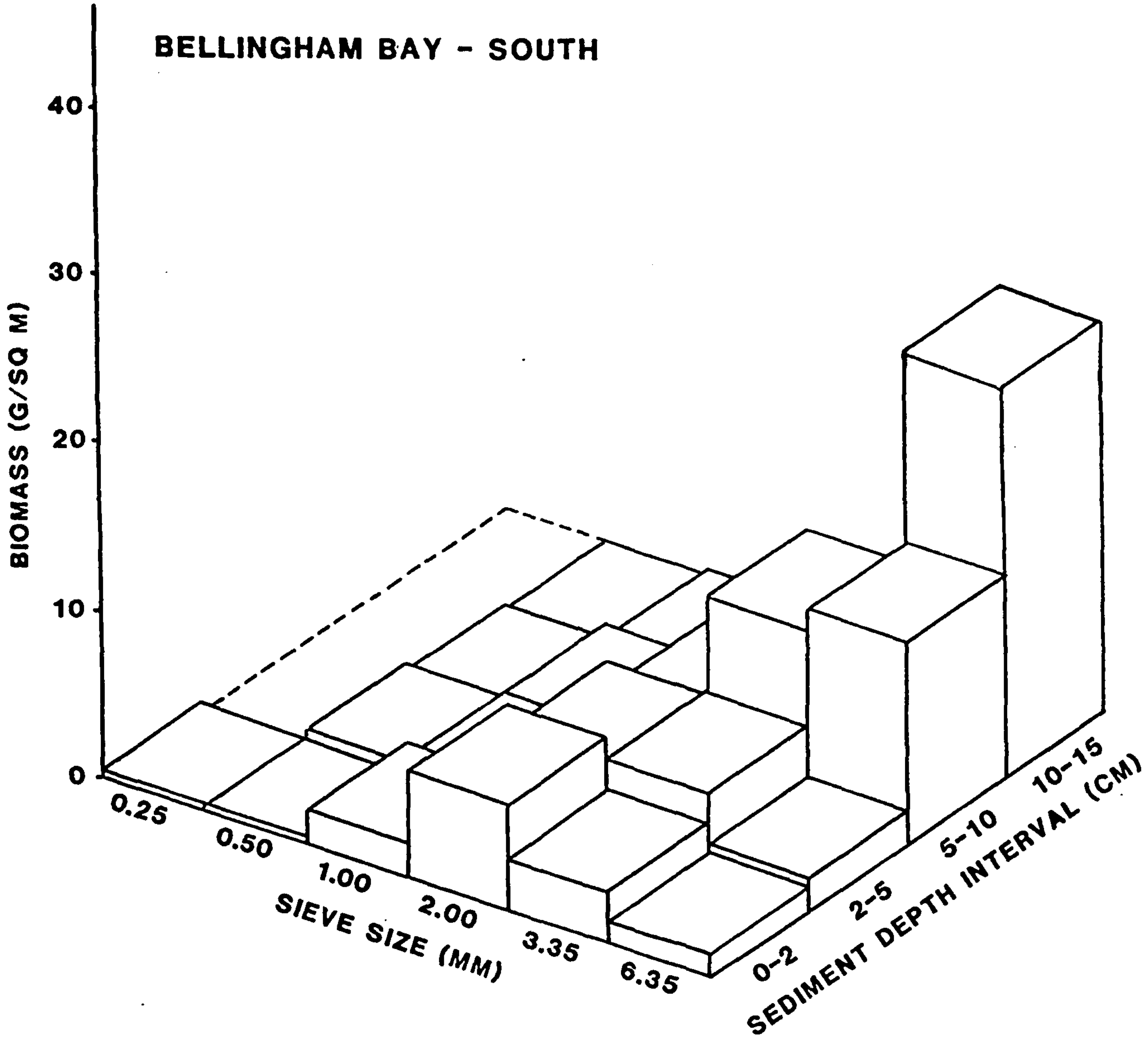


Figure 12. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Bellingham Bay South study area.

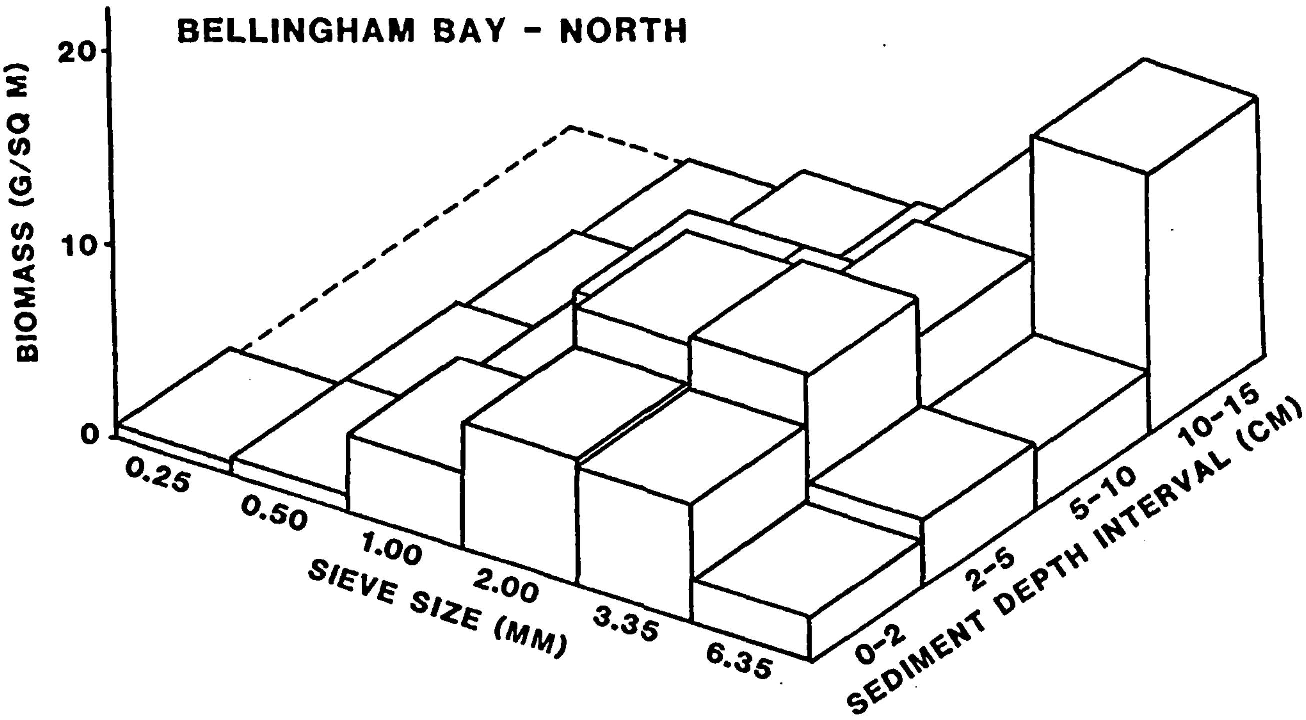


Figure 13. Three dimensional plot of benthic biomass across size categories and sediment depth intervals for the Bellingham Bay North study area.

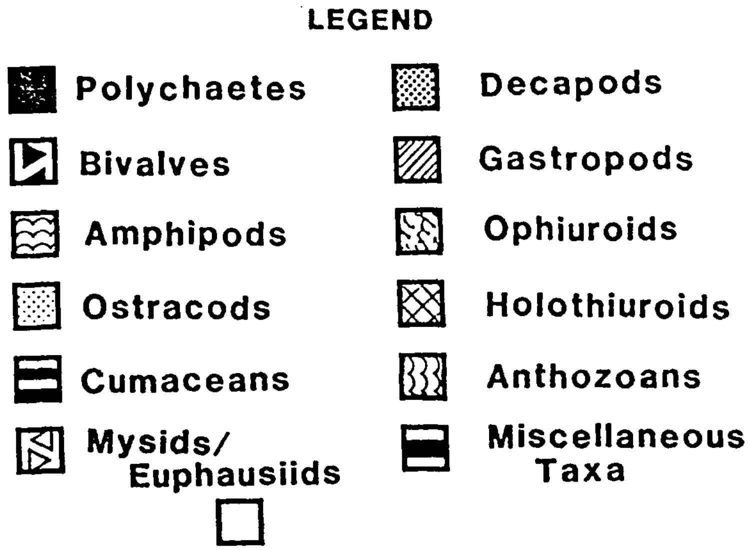
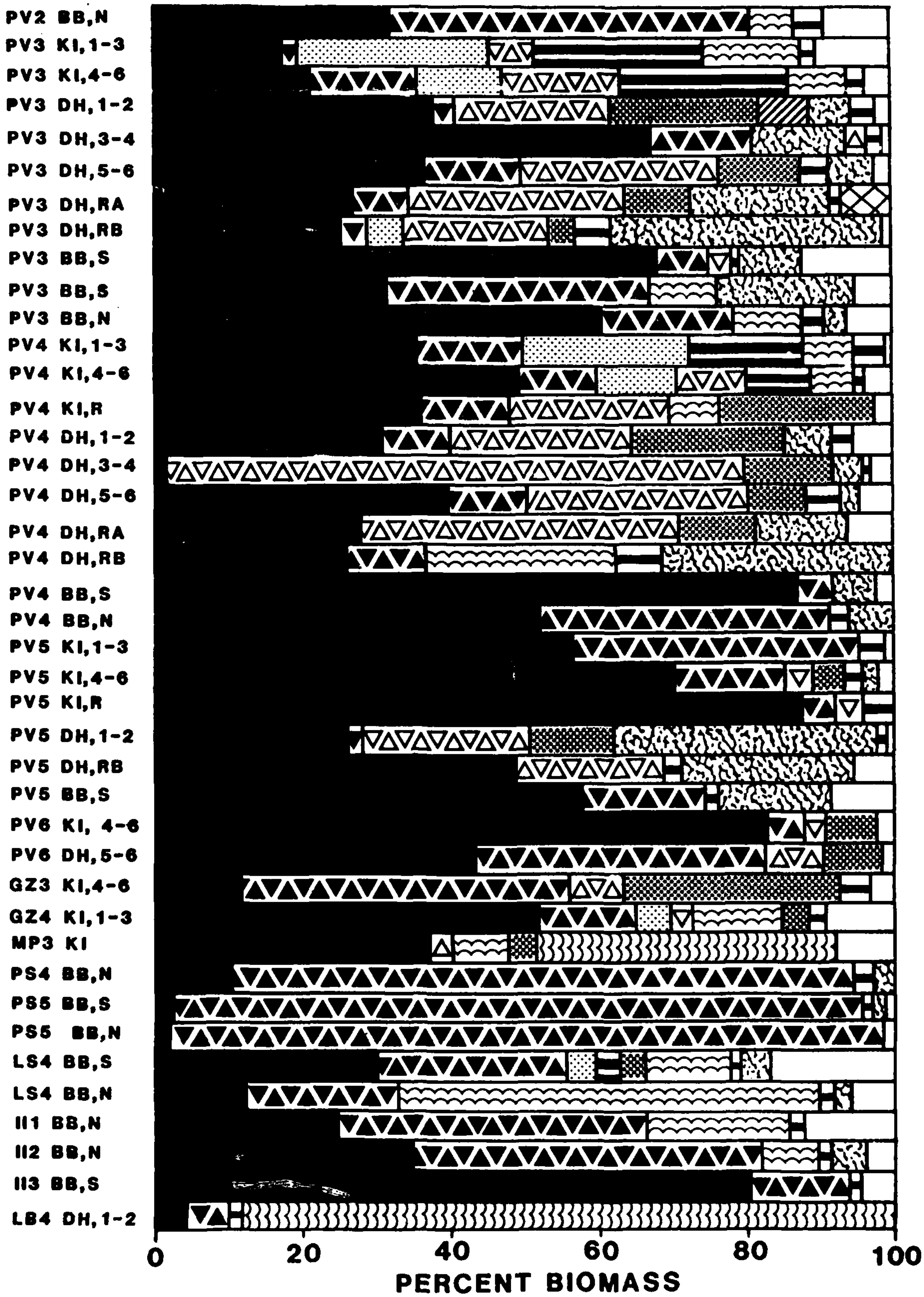


Figure 14. Taxonomic composition of the diets of fishes sampled in the Puget Sound study areas. PV = English sole, MP = Dover sole, II = butter sole, GZ = rex sole, PS = starry flounder, LB = rock sole, LS = snake prickleback, DH = Anderson Island/Devil's Head, KI = Anderson Island/Ketron Island, BB = Bellingham Bay. Number following species code indicates size class (cm SL). 1 = 5-9.9. 2 = 10-14.9, 3 = 15-19.9, 4 = 20-24.9, 5 = 25-29.9, 6 = 30-34.9. See text for trawl location designations.


PV2 BB,N
PV3 KI,1-3
PV3 KI,4-6
PV3 DH,1-2
PV3 DH,3-4
PV3 DH,5-6
PV3 DH,RA
PV3 DH,RB
PV3 BB,S
PV3 BB,S
PV3 BB,N
PV4 KI,1-3
PV4 KI,4-6
PV4 KI,R
PV4 DH,1-2
PV4 DH,3-4
PV4 DH,5-6
PV4 DH,RA
PV4 DH,RB
PV4 BB,S
PV4 BB,N
PV5 KI,1-3
PV5 KI,4-6
PV5 KI,R
PV5 DH,1-2
PV5 DH,RB
PV5 BB,S
PV6 KI, 4-6
PV6 DH,5-6
GZ3 KI,4-6
GZ4 KI,1-3
MP3 KI
PS4 BB,N
PS5 BB,S
PS5 BB,N
LS4 BB,S
LS4 BB,N
II1 BB,N
II2 BB,N
II3 BB,S
LB4 DH,1-2
0
20
40
60
80
100
PERCENT BIOMASS

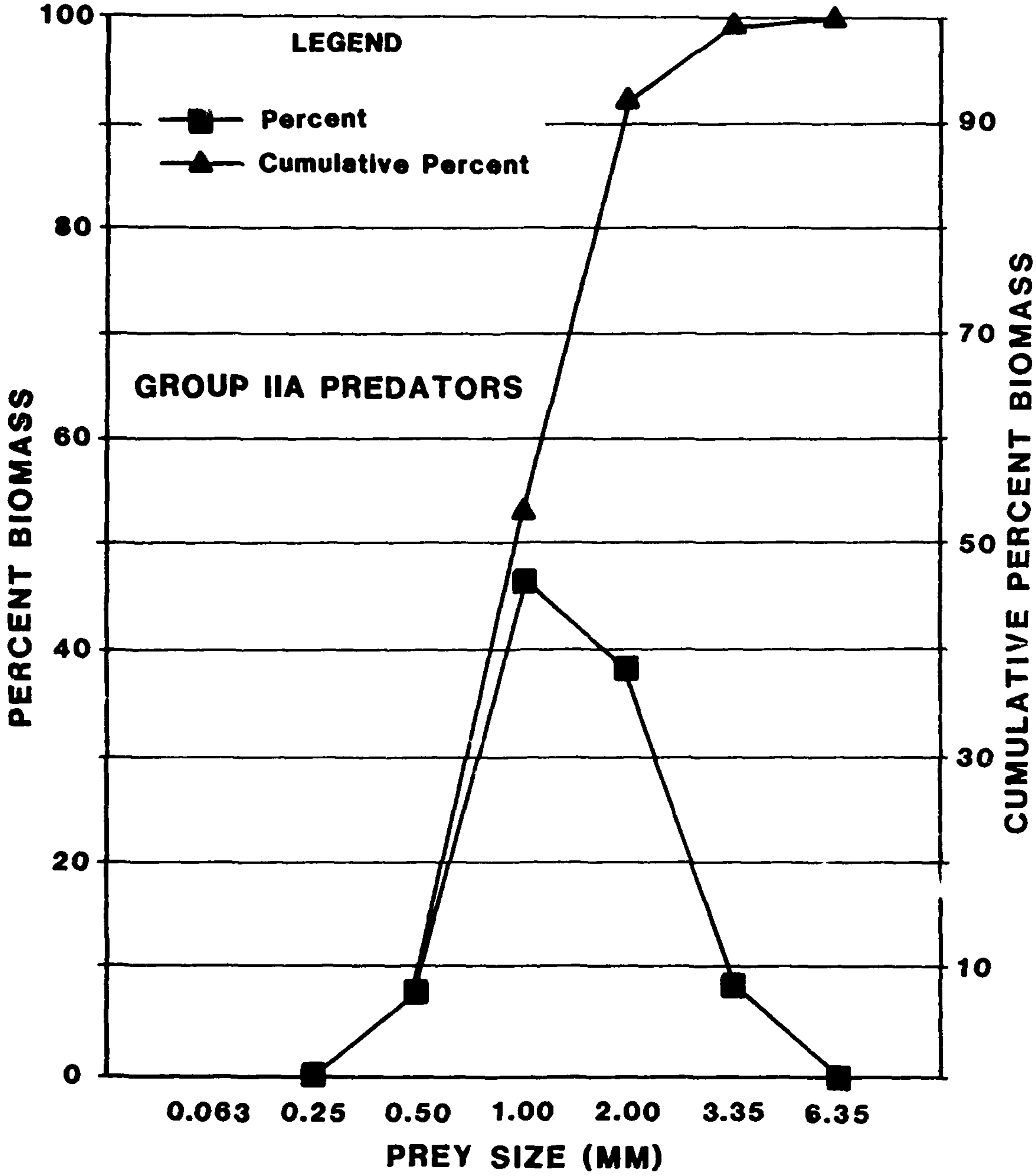


Figure 15. Prey size exploitation pattern for predators in Group IIA.

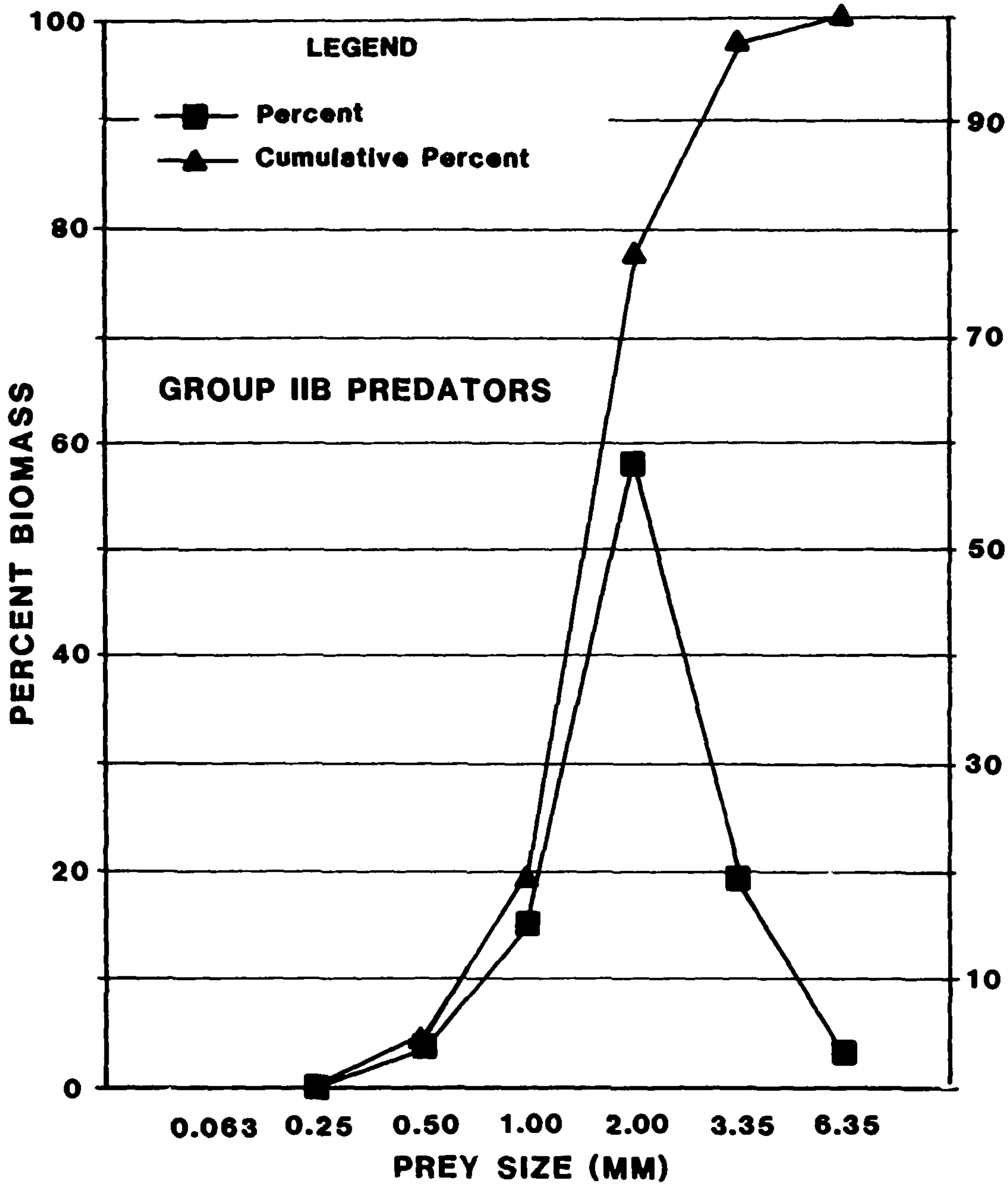


Figure 16. Prey size exploitation pattern for predators in Group IIB.

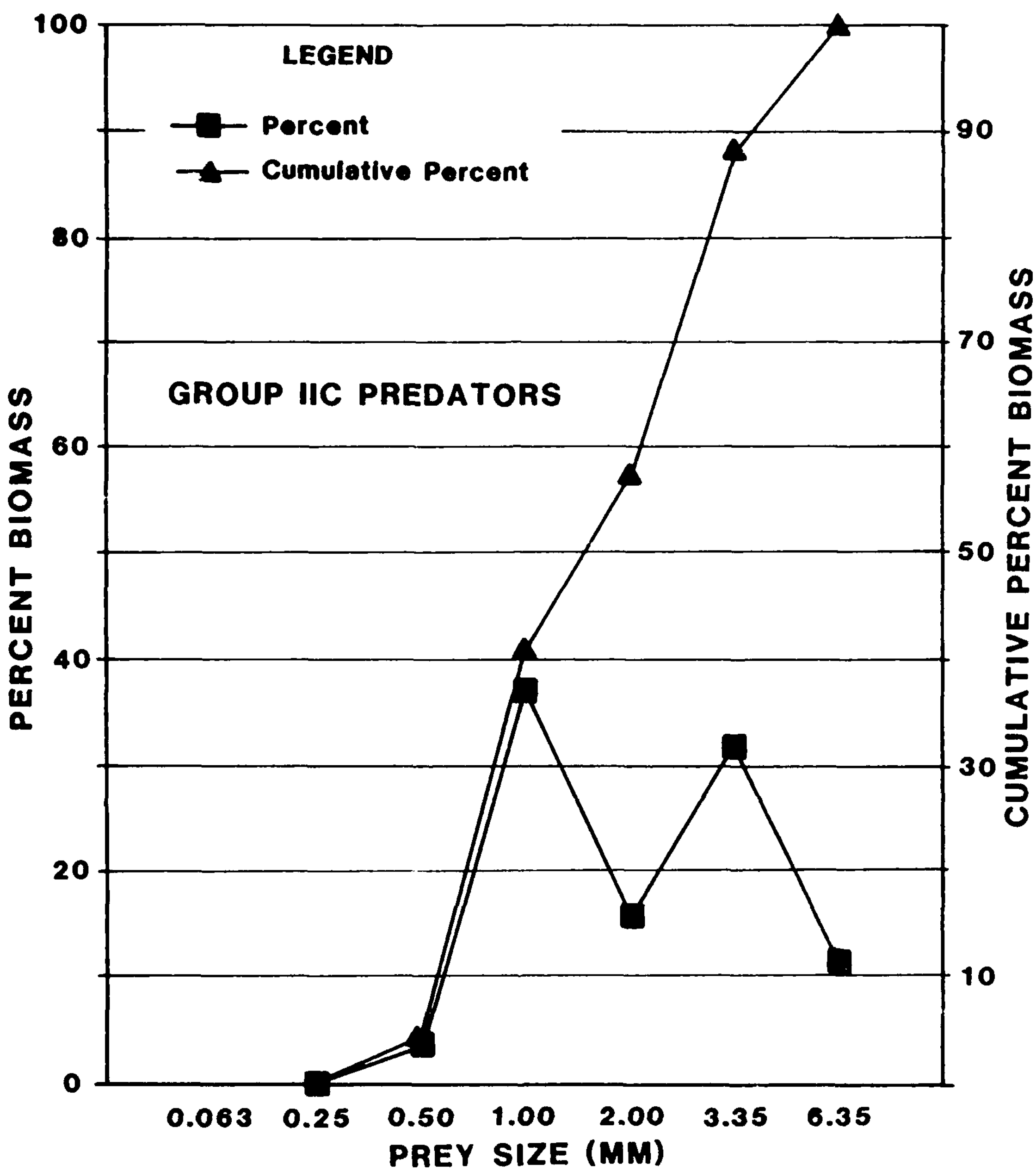


Figure 17. Prey size exploitation pattern for predators in Group IIC.

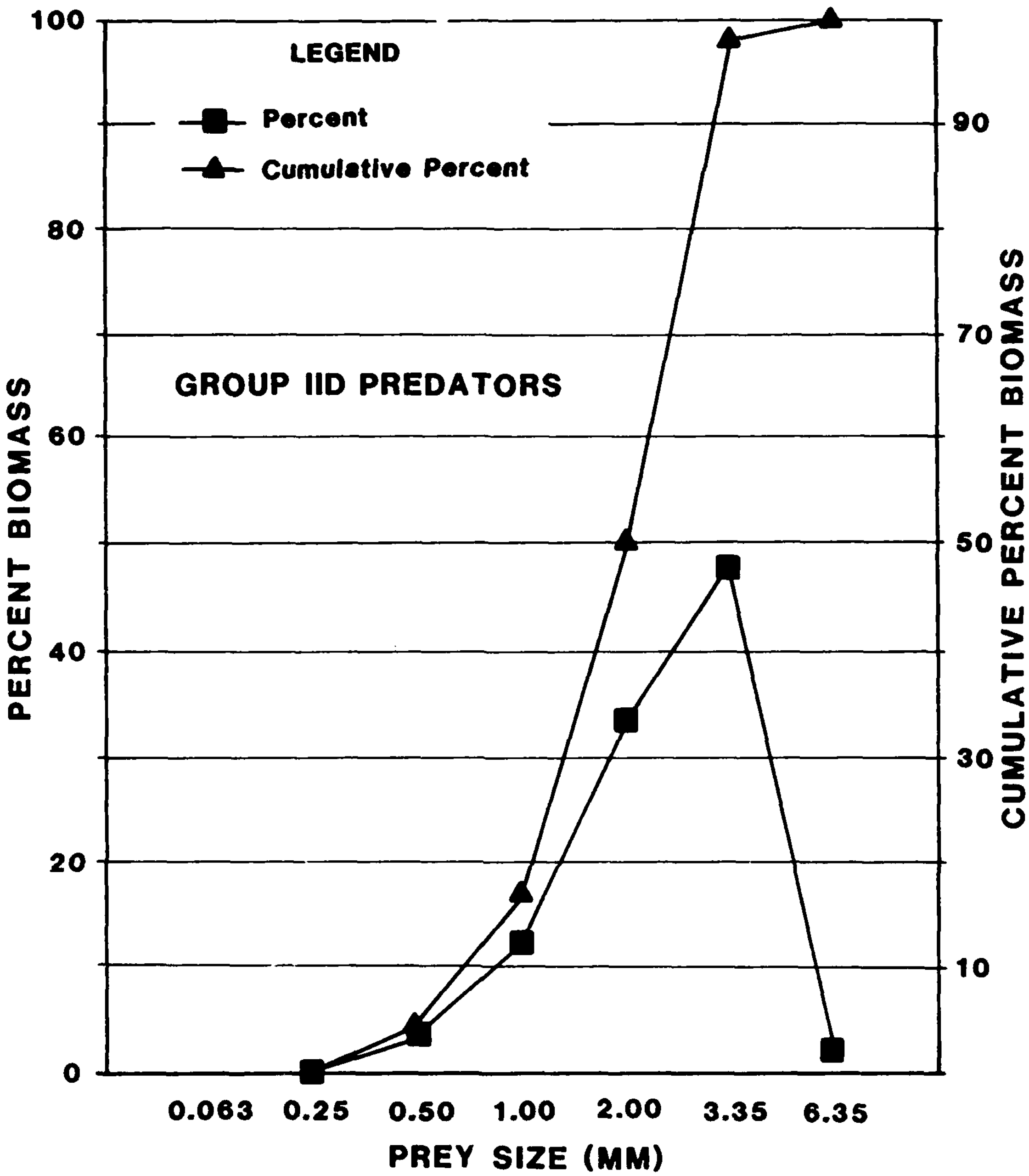


Figure 18. Prey size exploitation pattern for predators in Group IID.

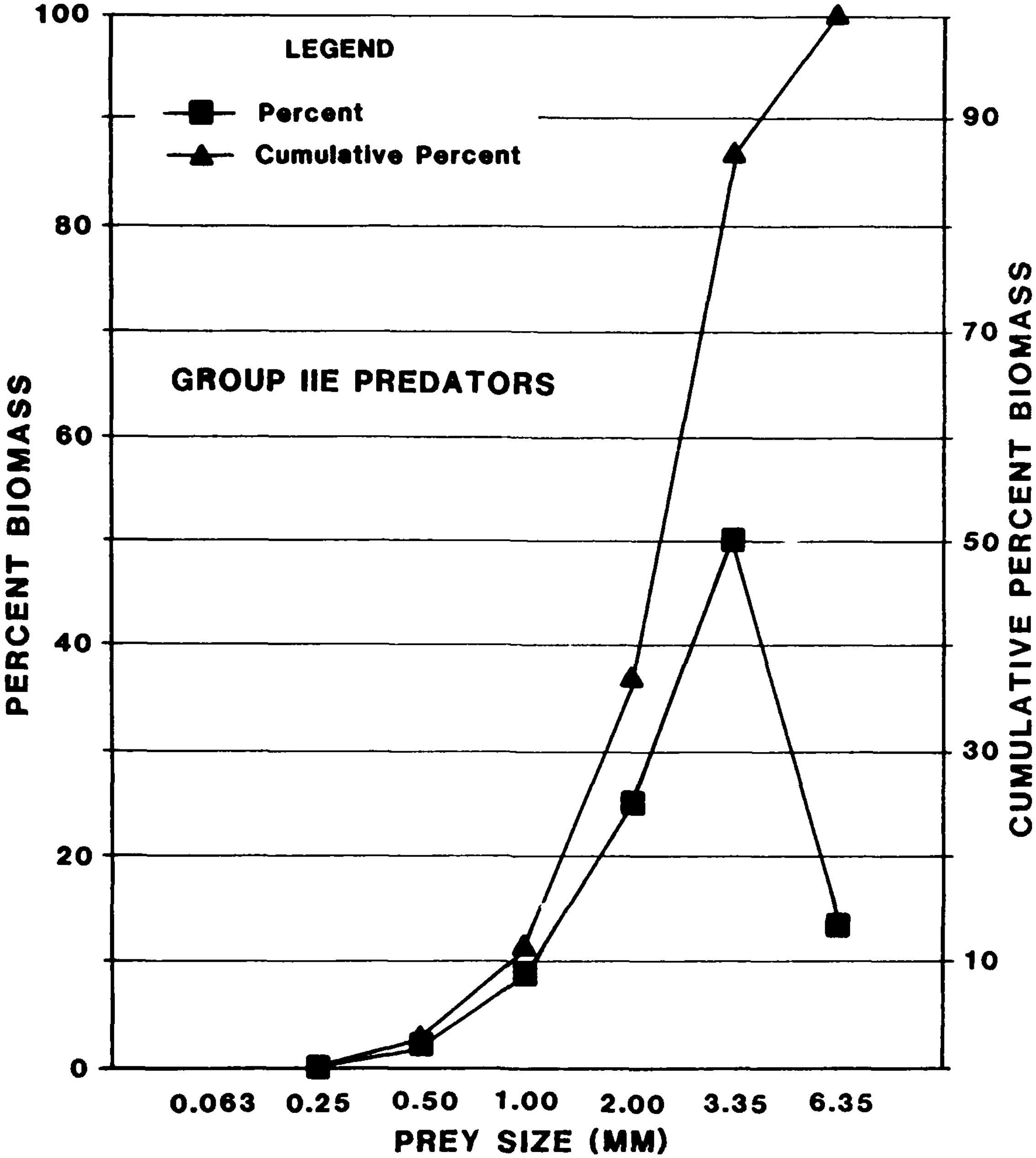


Figure 19. Prey size exploitation pattern for predators in Group IIE.

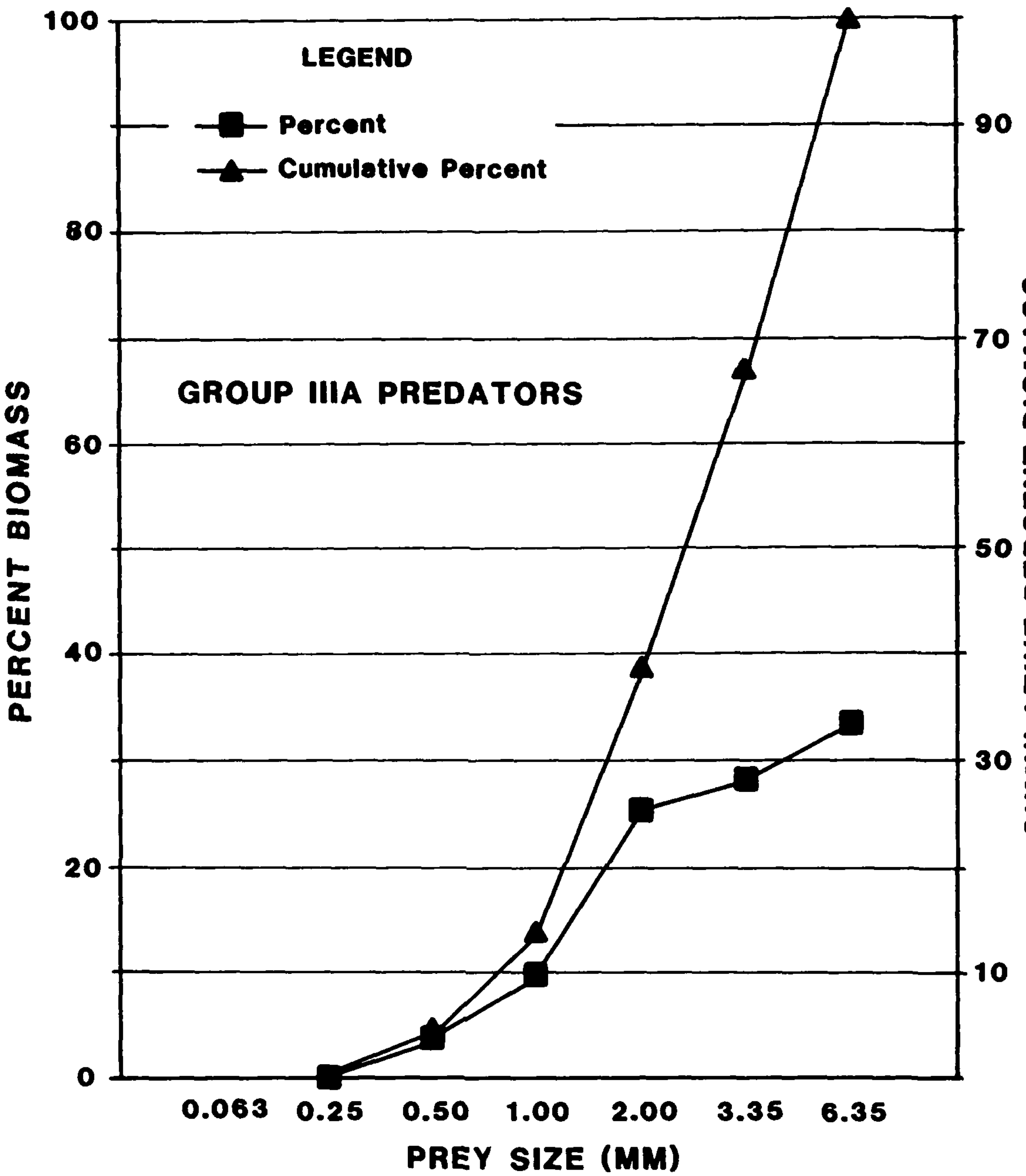


Figure 20. Prey size exploitation pattern for predators in Group IIIA.

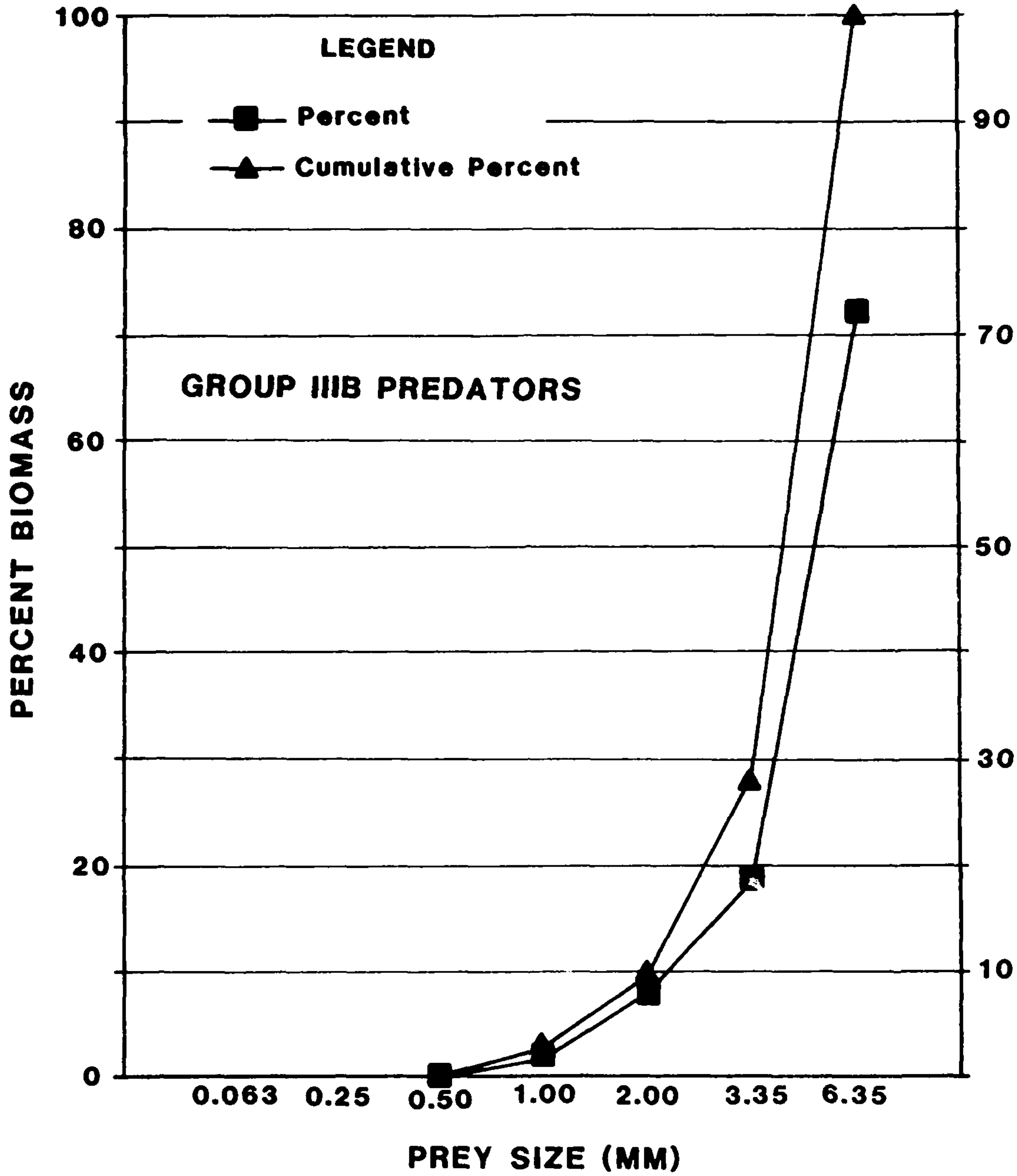
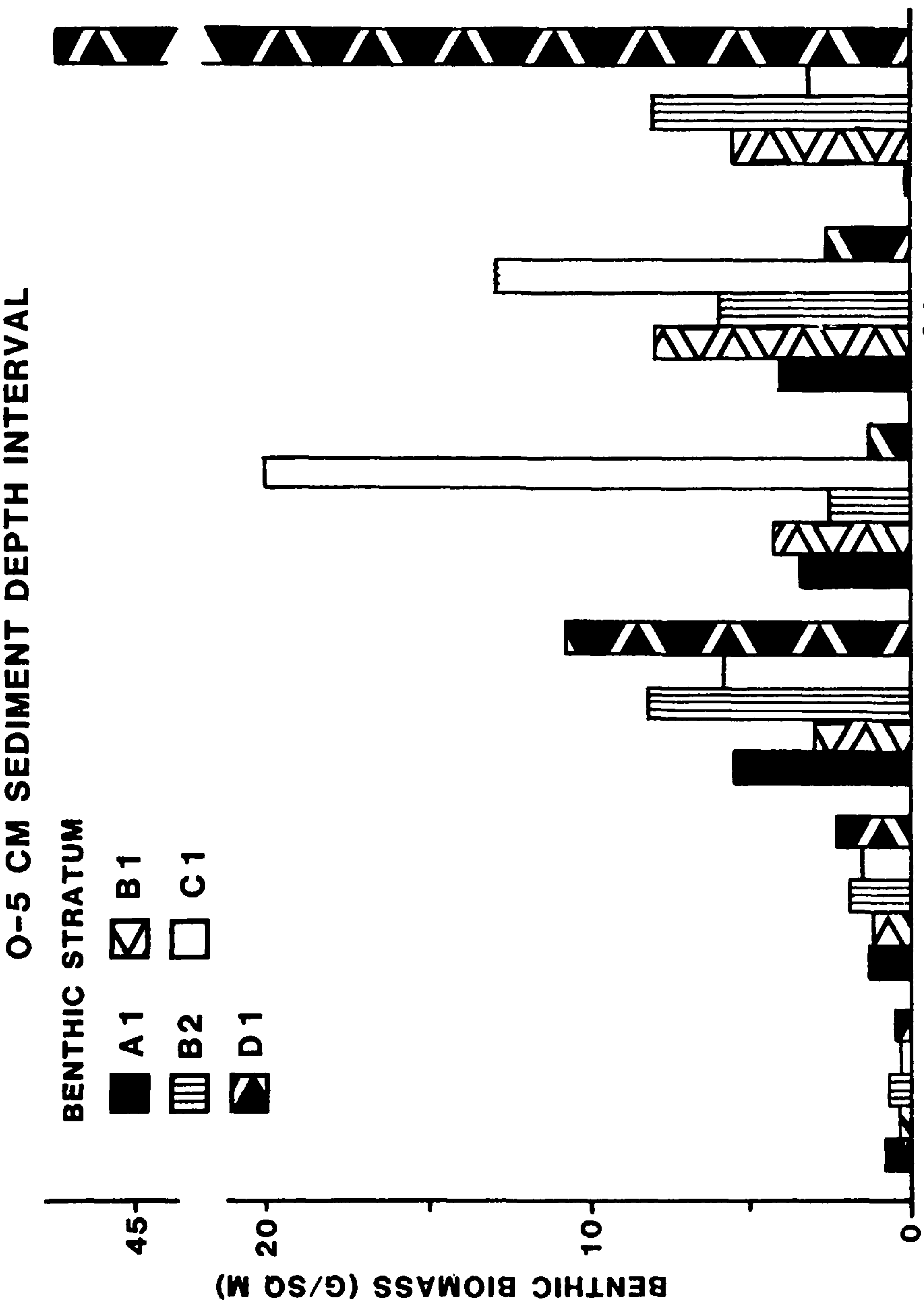


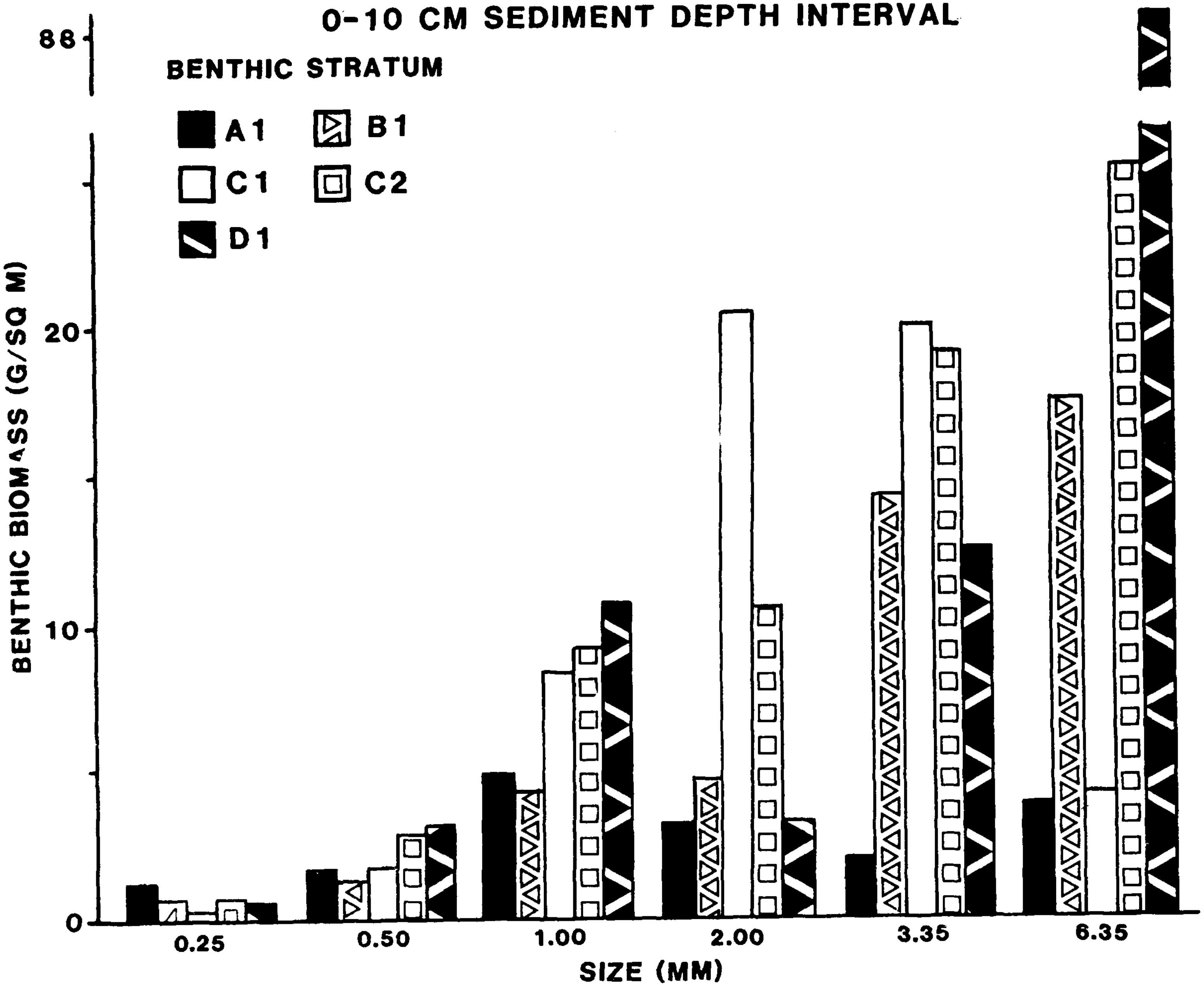
Figure 21. Prey size exploitation pattern for predators in Group IIIB.

Figure 22. Size distribution of benthic biomass among benthic strata in the 0-5 cm sediment depth interval for the Puget Sound study areas.



O-5 CM SEDIMENT DEPTH INTERVAL
BENTHIC STRATUM
A1
B1
B2
C1
D1
BENTHIC BIOMASS (G/SQ M)
0
10
20
45
SIZE (MM)
0.25
0.50
1.00
2.00
3.35
6.35

Figure 23. Size distribution of benthic biomass among benthic strata in the 0-10 cm sediment depth interval for the Puget Sound study areas.



0-10 CM SEDIMENT DEPTH INTERVAL
BENTHIC STRATUM
A1
B1
C1
C2
D1
BENTHIC BIOMASS (G/SQ M)
88
20
10
0
0.25
0.50
1.00
2.00
3.35
6.35
SIZE (MM)

Figure 24. Distribution of potential trophic resource value among benthic biomass strata for various predator feeding groups in the Puget Sound study areas.

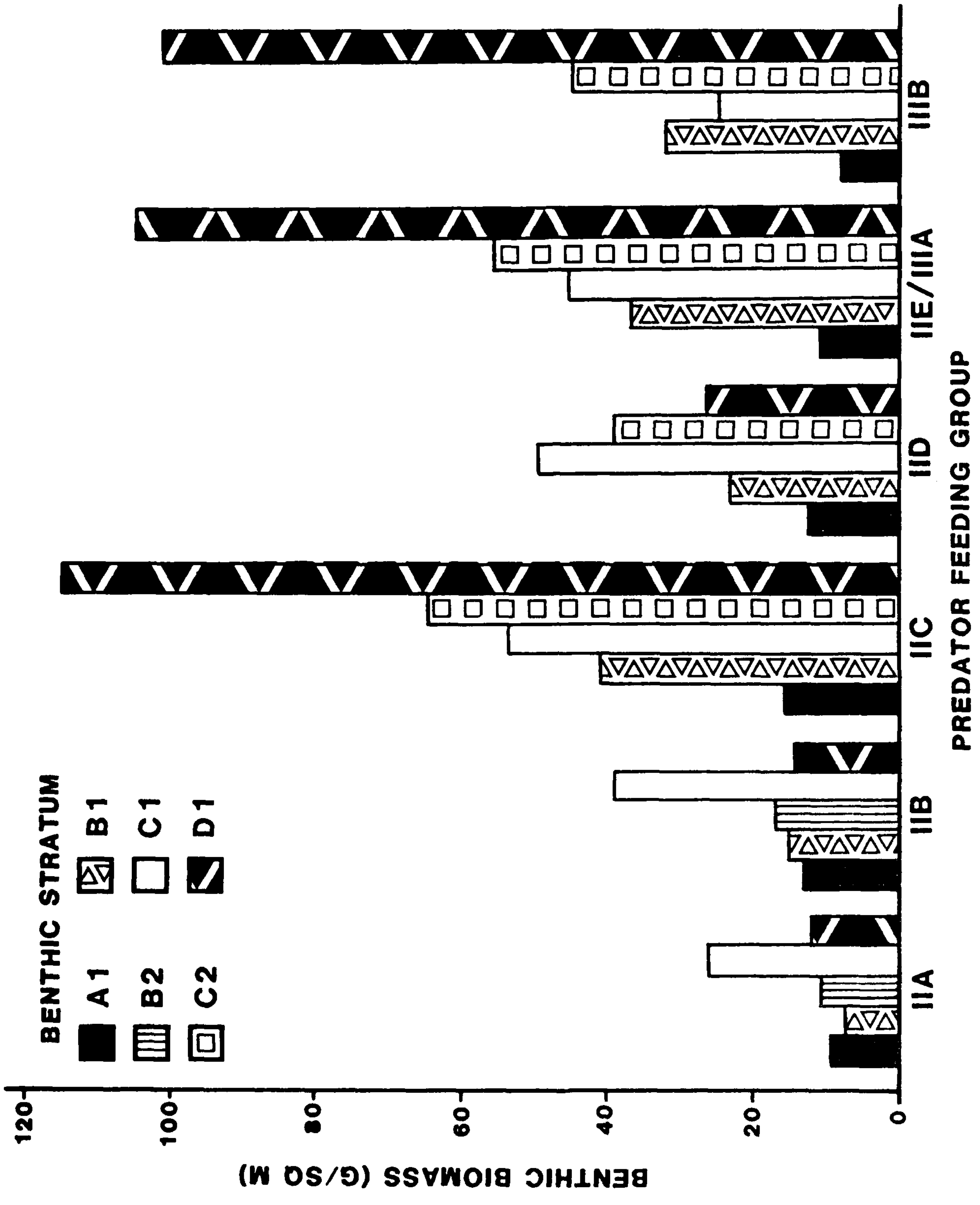

BENTHIC STRATUM
A1
B1
B2
C1
C2
D1
BENTHIC BIOMASS (G/SQ M)
0
20
40
60
80
100
120
IIA
IIB
IIC
IID
IIE/IIIA
IIIB
PREDATOR FEEDING GROUP

Table 1. Size distribution of total benthic biomass (pooled across all vertical sediment depth fractions) among study areas. Table values are in g/sq m. DH = Anderson Island/Devil's Head, KI = Anderson Island/Ketron Island, BB = Bellingham Bay, D = Disposal Area, R = Reference, A = South Site, B = North Site

		Biomass Size Category (mm)						
Taxon		0.25	0.50	1.00	2.00	3.35	6.35	Total
Bivalvia	DH-D	0.049	0.110	0.492	0.627	0.760	0.000	2.037
	DH-R	0.048	0.127	0.327	0.358	0.534	0.000	1.395
	KI-D	0.016	0.114	0.521	0.647	6.192	6.105	13.594
	BB-A	0.008	0.126	1.250	10.021	7.282	21.846	40.534
	BB-B	0.053	0.110	2.097	9.436	7.090	4.140	22.927
Polychaeta	DH-D	0.147	1.227	3.635	2.616	7.206	31.430	46.260
	DH-R	0.238	1.140	1.879	1.644	7.686	24.349	36.936
	KI-D	0.216	0.720	1.266	2.060	11.333	35.430	51.025
	BB-A	0.040	1.037	1.720	3.489	10.215	12.391	28.881
	BB-B	0.169	1.296	5.783	7.029	13.983	3.619	31.878
Crustacea	BB-A	0.012	0.055	0.455	0.000	0.000	0.000	0.521
	BB-B	0.000	0.088	0.374	0.000	0.000	0.000	0.462
Nematoda	DH-D	0.156	0.028	0.000	0.000	0.000	0.000	0.185
	DH-R	0.032	0.037	0.000	0.000	0.000	0.000	0.069
	KI-D	0.044	0.021	0.000	0.000	0.000	0.000	0.065
	BB-A	0.109	0.018	0.000	0.000	0.000	0.000	0.127
	BB-B	0.028	0.024	0.000	0.000	0.000	0.000	0.052
Gastropoda	DH-D	0.000	0.003	0.053	0.244	0.288	1.612	2.200
	DH-R	0.000	0.000	0.146	0.305	1.829	0.000	2.279
	KI-D	0.000	0.007	0.076	0.135	0.800	0.000	1.018
	BB-A	0.003	0.018	0.090	0.105	0.848	0.571	1.634
	BB-B	0.000	0.045	0.022	0.202	0.593	0.390	1.253
Ostracoda	DH-D	0.421	0.462	2.295	0.000	0.000	0.000	3.179
	DH-R	0.669	0.361	1.831	0.000	0.000	0.000	2.861
	KI-D	0.167	1.711	8.052	0.845	0.000	0.000	10.774
	BB-A	0.007	0.007	0.102	0.000	0.000	0.000	0.116
Copepoda	DH-D	0.293	0.065	0.000	0.000	0.000	0.000	0.357
	DH-R	0.134	0.120	0.000	0.000	0.000	0.000	0.254
	KI-D	0.014	0.019	0.000	0.000	0.000	0.000	0.033
	BB-A	0.034	0.029	0.000	0.000	0.000	0.000	0.063
	BB-B	0.070	0.012	0.000	0.000	0.000	0.000	0.082

(continued)

Table 1. (concluded)

Taxon		Biomass Size Category (mm) 0.25	0.50	1.00	2.00	3.35	6.35	Total
Mysidacea	DH-D	0.000	0.000	0.016	0.000	0.340	0.085	0.441
	DH-R	0.000	0.012	0.043	0.281	1.071	0.086	1.492
	KI-D	0.000	0.013	0.107	0.115	0.000	0.000	0.234
	BB-A	0.000	0.000	0.003	0.000	0.000	0.000	0.003
	BB-B	0.000	0.000	0.005	0.000	0.517	0.000	0.522
Amphipoda	DH-D	0.012	0.149	0.271	0.443	0.434	1.488	2.800
	DH-R	0.029	0.071	0.315	0.102	0.000	0.000	0.517
	KI-D	0.051	0.183	0.761	0.345	0.000	0.000	1.340
	BB-A	0.011	0.038	0.303	0.151	0.005	0.000	0.508
	BB-B	0.040	0.375	1.507	1.186	0.000	0.000	3.108
Decapoda	DH-D	0.000	0.002	0.129	0.430	0.195	0.000	0.756
	DH-R	0.000	0.016	0.123	0.716	0.317	0.180	1.351
	KI-D	0.000	0.008	0.144	0.489	0.190	0.651	1.481
	BB-A	0.000	0.007	0.211	0.050	0.108	0.000	0.376
	BB-B	0.000	0.031	0.877	0.620	0.000	0.000	1.528
Insecta	DH-D	0.068	0.000	0.000	0.000	0.000	0.000	0.068
	DH-R	0.105	0.000	0.000	0.000	0.000	0.000	0.105
	BB-A	0.053	0.000	0.000	0.000	0.000	0.000	0.053
	BB-B	0.041	0.000	0.000	0.000	0.000	0.000	0.041
Ophiuroidea	DH-D	0.000	0.224	0.633	0.827	2.920	1.109	5.714
	DH-R	0.006	0.536	0.896	3.328	2.707	1.350	8.824
	KI-D	0.000	0.019	0.016	0.015	0.061	0.000	0.112
	BB-A	0.003	0.091	0.334	1.393	1.369	0.304	3.493
	BB-B	0.000	0.107	0.333	0.614	4.371	2.369	7.794
Holothur-oidea	DH-D	0.000	0.000	0.008	0.024	0.000	0.000	0.032
	DH-R	0.000	0.000	0.020	0.000	0.000	0.000	0.020
Other Taxa	DH-D	0.027	0.042	0.201	0.728	2.019	1.037	4.054
	DH-R	0.017	0.036	0.240	0.198	0.173	6.704	7.368
	KI-D	0.037	0.035	0.090	0.184	0.567	31.424	32.337
	BB-A	0.001	0.004	0.068	0.144	0.824	3.493	4.535
	BB-B	0.000	0.025	0.089	0.261	2.408	11.617	14.401

Table 2. Distribution of fish food habits samples among proposed dredged material disposal sites in Puget Sound. Fish size classes listed as Standard Length (SL). ZSF = Zone of Siting Feasibility, BB = Bellingham Bay. n = number of individual stomachs containing identifiable prey.

DISPOSAL AREA	ZSF 2		ZSF 3		BB	
	SL(cm)	n	SL(cm)	n	SL(cm)	n
SPECIES						
English Sole					10-14.9	2
	15-19.9	27	15-19.9	103	15-19.9	21
	20-24.9	81	20-24.9	64	20-24.9	11
	25-29.9	21	25-29.9	15	25-29.9	4
	30-34.9	3	30-34.9	3		
Rex Sole	15-19.9	3				
	20-29.9	8				
Dover Sole	15-24.9	7				
Rock Sole			20-29.9	4		
Butter Sole					5-9.9	3
					10-14.9	13
					15-24.9	2
Starry Flounder					20-24.9	4
					25-29.9	14
Snake Prickleback					20-29.9	89

TOTALS

DISPOSAL AREA	ZSF 2	ZSF 3	BB
	150	189	163

SPECIES	English Sole	Rex Sole	Dover Sole	Rock Sole	Butter Sole	Starry Flounder	Snake Prickleback
	355	11	7	4	18	18	89

Table 3. Description of prey size feeding strategy groups.

Group I - Fishes feeding on prey less than or equal to 1.0 mm or smaller with a modal prey size around 0.25 mm. No representatives of this group were found in this data set.

Group II - Fishes that exploit a range of prey sizes and that are not clearly small prey or large prey exploiters. Group II contains five subgroups in this data set.

Group IIA - Fishes that exploit prey between 0.5 and 3.35 mm. A prey size mode of 1.0 mm is indicated for benthic prey items.

Group IIB - Fishes that exploit prey between 1.0 and 3.35 mm. A prey size mode of 2.0 mm is indicated.

Group IIC - Fishes that exploit prey between 1.0 and 6.35 mm. Prey size distribution is bimodal, having separate peaks of 1.0 and 3.35 mm.

Group IID - Fishes that exploit prey between 1.0 and 3.35 mm, with a size mode of 3.35 mm.

Group IIE - Fishes that exploit prey between 1.0 and 6.35 mm, with a prey size mode of 3.35 mm.

Group III - Fishes that do not exploit small sized prey. Exploitation is predominantly among prey that are greater than 3.35 mm. Two subgroups occur in this data set.

Group IIIA - Fishes that exploit prey in the intermediate size range (1.0-3.35 mm), as well as the larger sizes with a prey size mode of 6.35 mm.

Group IIIB - Fishes that predominantly exploit prey in the 3.35 and 6.35 mm size range, with a distinct 6.35 mm prey size mode.

Table 4. Composition of feeding strategy groups based on prey size exploitation patterns.

GROUP	SPECIES	SIZE CLASS (cm, SL)	NUMBER OF INDIVIDUALS	SITE
IIA	English Sole	15-20	15	Ketron Island (1-3)
	English Sole	15-20	12	Ketron Island (4-6)
	English Sole	15-20	2	Bellingham Bay (South)
	Snake Prickleback	15-20	53	Bellingham Bay (South)
	Snake Prickleback	20-25	36	Bellingham Bay (North)
	Snake Prickleback	20-25	53	Bellingham Bay (South)
IIB	English Sole	15-20	32	Devils Head (1-2)
	English Sole	15-29	10	Devils Head (RB)
	Starry Flounder	20-25	4	Bellingham Bay (North)
	Starry Flounder	25-30	6	Bellingham Bay (South)
	Starry Flounder	25-30	8	Bellingham Bay (North)
	Butter Sole	5-10	3	Bellingham Bay (North)
IIC	English Sole	20-25	46	Ketron Island (1-3)
	English Sole	20-25	23	Ketron Island (4-6)
IID	Rex Sole	15-20	3	Ketron Island (4-6)
	English Sole	10-15	2	Bellingham Bay (North)
	English Sole	15-20	6	Bellingham Bay (South)
	English Sole	15-20	35	Devils Head (5-6)
	English Sole	15-20	13	Devils Head (RA)
	English Sole	20-25	22	Devils Head (1-2)
	English Sole	20-25	10	Devils Head (RA)
	English Sole	20-25	4	Devils Head (3-4)
	English Sole	20-25	13	Devils Head (5-6)
	English Sole	20-25	15	Devils Head (RB)
	English Sole	25-30	6	Devils Head (1-2)
	English Sole	25-30	9	Devils Head (RB)
	Butter Sole	10-15	13	Bellingham Bay (North)
IIE	English Sole	20-25	12	Ketron Island (R)
	English Sole	30-35	3	Ketron Island (4-6)
	Dover Sole	15-20	7	Ketron Island (1-3)
	Rex Sole	20-25	8	Ketron Island (1-3)
IIIA	Rock Sole	20-25	4	Devils Head (1-2)
	English Sole	15-20	13	Devils Head (3-4)
	English Sole	15-20	13	Bellingham Bay (North)
	English Sole	20-25	8	Bellingham Bay (North)
	English Sole	20-25	4	Bellingham Bay (South)
	English Sole	25-30	3	Devils Head (5-6)
	English Sole	25-30	6	Ketron Island (4-6)

(continued)

Table 4. (concluded)

GROUP	SPECIES	SIZE CLASS (SL, cm)	NUMBER OF INDIVIDUALS	SITE
IIIB	English Sole	20-25	4	Bellingham Bay (South)
	English Sole	25-30	7	Ketron Island (1-3)
	English Sole	25-30	8	Ketron Island (RA)
	Butter Sole	15-20	2	Bellingham Bay (South)

Table 5. Feeding efficiency of fishes sampled at three disposal areas in Puget Sound, as indicated by mean weight of food items per stomach. SL = Standard Length category in cm (1 = 5-9.9, 2 = 10-14.9, 3 = 15-19.9, 4 = 20-24.9, 5 = 25-29.9, 6 = >30). DH = Anderson Island/Devils Head (ZSF 3), KI = Anderson Island/Ketron Island (ZSF 2), BB = Bellingham Bay. Trawl designations given for each study area (R = reference, S = South, N = North)

SPECIES	SL	Mean Weight of Food Per Stomach (g)									
		DH					KI			BB	
		1-2	3-4	5-6	RA	RB	1-3	4-6	R	S	N
English Sole	2	-	-	-	-	-	-	-	-	-	0.375
	3	0.092	0.138	0.081	0.139	0.113	0.066	0.060	-	0.317	0.330
										0.188	
	4	0.332	0.199	0.213	0.116	0.438	0.150	0.231	0.183	1.791	0.380
	5	0.590	-	-	-	0.955	0.497	0.702	1.122	0.351	-
	6	-	-	0.288	-	-	-	0.670	-	-	-
Rock Sole	4	1.078	-	-	-	-	-	-	-	-	-
Rex Sole	3	-	-	-	-	-	-	0.233	-	-	-
	4	-	-	-	-	-	0.292	-	-	-	-
Dover Sole	3	-	-	-	-	-	0.219	-	-	-	-
Starry Flounder	4	-	-	-	-	-	-	-	-	-	0.986
	5	-	-	-	-	-	-	-	-	1.149	0.685
Butter Sole	1	-	-	-	-	-	-	-	-	-	0.127
	2	-	-	-	-	-	-	-	-	-	0.272
	3	-	-	-	-	-	-	-	-	0.365	-
Snake Prickle-back	4	-	-	-	-	-	-	-	-	0.036	0.064

Table 6. Mean biomass (g/sq m) of non-excluded taxa within different sediment depth fractions for benthic strata in the Puget Sound study areas.

	Size (mm) 0.25	0.50	1.00	2.00	3.35	6.35
Depth Fraction:0-2 cm						
Stratum A1	0.096	0.139	0.274	0.070	0.000	0.000
A2	0.955	0.916	3.745	0.780	2.141	0.048
A3	0.323	0.413	2.473	4.950	4.212	0.000
B1	0.259	1.292	8.075	5.076	0.032	0.000
B2	0.382	0.377	1.575	4.444	4.444	2.520
C1	0.547	1.604	7.337	2.433	2.039	21.249
Depth Fraction:0-5 cm						
Stratum A1	0.865	1.222	5.513	3.398	4.055	0.043
B1	0.419	1.104	2.985	4.268	7.985	5.636
B2	0.525	1.909	8.185	2.514	6.019	8.002
C1	0.330	1.476	5.979	20.082	12.932	3.106
D1	0.491	2.330	10.740	1.259	2.723	47.550
Depth Fraction:0-10 cm						
Stratum A1	1.346	1.776	4.908	3.140	4.034	3.808
B1	0.634	1.332	4.366	4.687	14.381	17.641
C1	0.309	1.797	8.295	20.583	20.464	4.293
C2	0.617	2.918	9.269	10.588	19.142	25.666
D1	0.578	3.135	10.776	3.268	12.612	88.707
Depth Fraction:0-15 cm						
Stratum A1	1.437	1.795	4.873	5.326	5.313	8.834
B1	0.652	1.561	5.518	5.207	18.617	20.323
B2	0.366	1.717	8.861	24.797	16.125	8.255
C1	0.665	2.526	8.660	13.980	28.879	38.407
D1	0.533	3.264	10.863	5.418	20.591	122.382

Table 7. Benthic resource analysis for Group IIA predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-5	0.865	0.000
0.50	-	"	1.222	0.000
1.00	+	"	5.513	5.513
2.00	+	"	3.398	3.398
3.35	-	"	4.055	0.000
6.35	-	"	0.043	0.000
				8.911
Stratum B1				
0.25	-	0-5	0.419	0.000
0.50	-	"	1.104	0.000
1.00	+	"	2.985	2.985
2.00	+	"	4.268	4.268
3.35	-	"	7.985	0.000
6.35	-	"	5.636	0.000
				7.253
Stratum B2				
0.25	-	0-5	0.525	0.000
0.50	-	"	1.909	0.000
1.00	+	"	8.185	8.185
2.00	+	"	2.514	2.514
3.35	-	"	6.019	0.000
6.35	-	"	8.002	0.000
				10.699
Stratum C1				
0.25	-	0-5	0.330	0.000
0.50	-	"	1.476	0.000
1.00	+	"	5.979	5.979
2.00	+	"	20.082	20.082
3.35	-	"	12.932	0.000
6.35	-	"	3.106	0.000
				26.061
Stratum D1				
0.25	-	0-5	0.491	0.000
0.50	-	"	2.330	0.000
1.00	+	"	10.740	10.740
2.00	+	"	1.259	1.259
3.35	-	"	2.723	0.000
6.35	-	"	47.550	0.000
				11.999

Table 8. Benthic resource analysis for Group IIB predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-5	0.865	0.000
0.50	-	"	1.222	0.000
1.00	+	"	5.513	5.513
2.00	+	"	3.398	3.398
3.35	+	"	4.055	4.055
6.35	-	"	0.043	0.000
				12.966
Stratum B1				
0.25	-	0-5	0.419	0.000
0.50	-	"	1.104	0.000
1.00	+	"	2.985	2.985
2.00	+	"	4.268	4.268
3.35	+	"	7.985	7.985
6.35	-	"	5.636	0.000
				15.238
Stratum B2				
0.25	-	0-5	0.525	0.000
0.50	-	"	1.909	0.000
1.00	+	"	8.185	8.185
2.00	+	"	2.514	2.514
3.35	+	"	6.019	6.019
6.35	-	"	8.002	0.000
				16.718
Stratum C1				
0.25	-	0-5	0.330	0.000
0.50	-	"	1.476	0.000
1.00	+	"	5.979	5.979
2.00	+	"	20.082	20.082
3.35	+	"	12.932	12.932
6.35	-	"	3.106	0.000
				38.993
Stratum D1				
0.25	-	0-5	0.491	0.000
0.50	-	"	2.330	0.000
1.00	+	"	10.740	10.740
2.00	+	"	1.259	1.259
3.35	+	"	2.723	2.723
6.35	-	"	47.550	0.000
				14.722

Table 9. Benthic resources analysis for Group IIC predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-10	1.346	0.000
0.50	-	"	1.776	0.000
1.00	+	"	4.908	4.908
2.00	+	"	3.140	3.140
3.35	+	"	4.034	4.034
6.35	+	"	3.808	3.808
				15.890
Stratum B1				
0.25	-	0-10	0.634	0.000
0.50	-	"	1.332	0.000
1.00	+	"	4.366	4.366
2.00	+	"	4.687	4.687
3.35	+	"	14.381	14.381
6.35	+	"	17.641	17.641
				41.075
Stratum C1				
0.25	-	0-10	0.309	0.000
0.50	-	"	1.797	0.000
1.00	+	"	8.295	8.295
2.00	+	"	20.583	20.583
3.35	+	"	20.464	20.464
6.35	+	"	4.293	4.293
				53.635
Stratum C2				
0.25	-	0-10	0.617	0.000
0.50	-	"	2.918	0.000
1.00	+	"	9.269	9.269
2.00	+	"	10.588	10.588
3.35	+	"	19.142	19.142
6.35	+	"	25.666	25.666
				64.665
Stratum D1				
0.25	-	0-10	0.578	0.000
0.50	-	"	3.135	0.000
1.00	+	"	10.776	10.776
2.00	+	"	3.268	3.268
3.35	+	"	12.612	12.612
6.35	-	"	88.707	88.707
				115.363

Table 10. Benthic resource analysis for Group IID predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-10	1.346	0.000
0.50	-	"	1.776	0.000
1.00	+	"	4.908	4.908
2.00	+	"	3.140	3.140
3.35	+	"	4.034	4.034
6.35	-	"	3.808	0.000
				12.082
Stratum B1				
0.25	-	0-10	0.634	0.000
0.50	-	"	1.332	0.000
1.00	+	"	4.366	4.366
2.00	+	"	4.687	4.687
3.35	+	"	14.381	14.381
6.35	-	"	17.641	0.000
				23.434
Stratum C1				
0.25	-	0-10	0.309	0.000
0.50	-	"	1.797	0.000
1.00	+	"	8.295	8.295
2.00	+	"	20.583	20.583
3.35	+	"	20.464	20.464
6.35	-	"	4.293	0.000
				49.342
Stratum C2				
0.25	-	0-10	0.617	0.000
0.50	-	"	2.918	0.000
1.00	+	"	9.269	9.269
2.00	+	"	10.588	10.588
3.35	+	"	19.142	19.142
6.35	-	"	25.666	0.000
				38.999
Stratum D1				
0.25	-	0-10	0.578	0.000
0.50	-	"	3.135	0.000
1.00	+	"	10.776	10.776
2.00	+	"	3.268	3.268
3.35	+	"	12.612	12.612
6.35	-	"	88.707	0.000
				26.656

Table 11. Benthic resource analysis for Group IIE predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-10	1.346	0.000
0.50	-	"	1.776	0.000
1.00	-	"	4.908	0.000
2.00	+	"	3.140	3.140
3.35	+	"	4.034	4.034
6.35	+	"	3.808	3.808
				10.982
Stratum B1				
0.25	-	0-10	0.634	0.000
0.50	-	"	1.332	0.000
1.00	-	"	4.366	0.000
2.00	+	"	4.687	4.687
3.35	+	"	14.381	14.381
6.35	+	"	17.641	17.641
				36.709
Stratum C1				
0.25	-	0-10	0.309	0.000
0.50	-	"	1.797	0.000
1.00	-	"	8.295	0.000
2.00	+	"	20.583	20.583
3.35	+	"	20.464	20.464
6.35	+	"	4.293	4.293
				45.340
Stratum C2				
0.25	-	0-10	0.617	0.000
0.50	-	"	2.918	0.000
1.00	-	"	9.269	0.000
2.00	+	"	10.588	10.588
3.35	+	"	19.142	19.142
6.35	+	"	25.666	25.666
				55.406
Stratum D1				
0.25	-	0-10	0.578	0.000
0.50	-	"	3.135	0.000
1.00	-	"	10.776	0.000
2.00	+	"	3.268	3.268
3.35	+	"	12.612	12.612
6.35	+	"	88.707	88.707
				104.587

Table 12. Benthic resource analysis for Group IIIA predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-10	1.346	0.000
0.50	-	"	1.776	0.000
1.00	-	"	4.908	0.000
2.00	+	"	3.140	3.140
3.35	+	"	4.034	4.034
6.35	+	"	3.808	3.808
				10.982
Stratum B1				
0.25	-	0-10	0.634	0.000
0.50	-	"	1.332	0.000
1.00	-	"	4.366	0.000
2.00	+	"	4.687	4.687
3.35	+	"	14.381	14.381
6.35	+	"	17.641	17.641
				36.709
Stratum C1				
0.25	-	0-10	0.309	0.000
0.50	-	"	1.797	0.000
1.00	-	"	8.295	0.000
2.00	+	"	20.583	20.583
3.35	+	"	20.464	20.464
6.35	+	"	4.293	4.293
				45.340
Stratum C2				
0.25	-	0-10	0.617	0.000
0.50	-	"	2.918	0.000
1.00	-	"	9.269	0.000
2.00	+	"	10.588	10.588
3.35	+	"	19.142	19.142
6.35	+	"	25.666	25.666
				55.406
Stratum D1				
0.25	-	0-10	0.578	0.000
0.50	-	"	3.135	0.000
1.00	-	"	10.776	0.000
2.00	+	"	3.268	3.268
3.35	+	"	12.612	12.612
6.35	+	"	88.707	88.707
				104.587

Table 13. Benthic resource analysis for Group IIIB predators.

Benthos Size (mm)	Vulnerable Size (mm)	Available Zone (cm)	Mean Biomass (g/sq m) in Available Zone	Potential Habitat Food Value (g/sq m)
Stratum A1				
0.25	-	0-10	1.346	0.000
0.50	-	"	1.776	0.000
1.00	-	"	4.908	0.000
2.00	-	"	3.140	0.000
3.35	+	"	4.034	4.034
6.35	+	"	3.808	3.808
				7.842
Stratum B1				
0.25	-	0-10	0.634	0.000
0.50	-	"	1.332	0.000
1.00	-	"	4.366	0.000
2.00	-	"	4.687	0.000
3.35	+	"	14.381	14.381
6.35	+	"	17.641	17.641
				32.022
Stratum C1				
0.25	-	0-10	0.309	0.000
0.50	-	"	1.797	0.000
1.00	-	"	8.295	0.000
2.00	-	"	20.583	0.000
3.35	+	"	20.464	20.464
6.35	+	"	4.293	4.293
				24.757
Stratum C2				
0.25	-	0-10	0.617	0.000
0.50	-	"	2.918	0.000
1.00	-	"	9.269	0.000
2.00	-	"	10.588	0.000
3.35	+	"	19.142	19.142
6.35	+	"	25.666	25.666
				44.808
Stratum D1				
0.25	-	0-10	0.578	0.000
0.50	-	"	3.135	0.000
1.00	-	"	10.776	0.000
2.00	-	"	3.268	0.000
3.35	+	"	12.612	12.612
6.35	+	"	88.707	88.707
				101.319